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EVALUATION OF PERSONAL COOLING SYSTEMS IN CONJUNCTION WITH EXPLOSIVE ORDNANCE DISPOSAL SUITS

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Table of Contents

Abstract

This study examined the capabilities of three technologies (a liquid cooled undergarment, a thickly-ribbed vest of hydrophylic nylon, and an air vest) to alleviate thermal strain in personnel working in Explosives Ordnance Disposal (EOD) clothing under environmental conditions of 18°C @ 40% relative humidity (rh), 34°C @ 40% rh, and 34°C @ 80% rh. Simulated EOD tasks consisted of treadmill walking (10 min), unstacking/carrying/stacking weighted boxes (10 min), and a rest period (15 min) with the EOD helmet and jacket removed repeated for a target duration time of 90 min. Physiological data included rectal temperature, skin temperature , heart rate , sweat production and evaporation, metabolic rate, and subjective evaluations of thermal comfort and perceived exertion. The results indicated that wearing the EOD suit produces significant increases in thermal physiological strain over performing the same tasks in a standard station uniform. However, the liquid-cooled Exotemp® personal cooling system was very effective in reducing that strain during heat exposure. Rectal temperatures, heart rates and fluid losses (dehydration) were reduced back to values comparable to those when not wearing the EOD suit, while skin temperatures were actually lower with the cooling system than with only the station uniform. Subjects indicated reduced perceived exertion levels and improved thermal comfort when wearing the liquid-cooled garment with the EOD suit. In contrast, the ribbed vest and air vest showed no significant benefits with the EOD suit. It is concluded that the increase in thermal physiological strain resulting from wearing the EOD suit during EOD work in hot environments can effectively be minimised by use of the Exotemp® personal cooling system.

EXECUTIVE SUMMARY

This study examined the capabilities of various technologies to alleviate thermal strain in personnel wearing Explosives Ordnance Disposal (EOD) suits during simulated EOD work under various environmental conditions. The technology of prime interest was the Exotemp® personal cooling system consisting of liquid-cooled undergarments (longjohns, undershirt and cooling cap) and a cooling fluid reservoir (plastic jug containing ice/water) with battery-powered pump. A second approach involved wearing a thickly-ribbed vest of hydrophylic nylon under the EOD suit, the idea being to create a space between the body and the suit for passive air circulation and sweat evaporation. A third technology extended the concept of air movement beneath the EOD suit by actively circulating ambient air between the body and the EOD suit using an air-cooled vest developed originally for military aircrew.

The study was conducted in the climatic chamber at the Defence and Civil Institute of Environmental Medicine (DCIEM) in Toronto. The test conditions included 18°C @ 40% relative humidity (rh), 34°C @ 40% rh, and 34°C @ 80% rh. In addition to tests with the experimental cooling garments, baseline tests with subjects wearing only standard station uniforms or the EOD suit without cooling were also conducted under each environmental condition. Simulated EOD tasks in the chamber consisted of treadmill walking (10 min @ 3.5 $km \cdot h^{-1}$) and unstacking/carrying (distance 2.5 m)/stacking weighted boxes (15 kg) for 10 minutes. The work phase was followed by a 15 min rest period in the chamber with the EOD helmet and jacket removed. This work/rest cycle was repeated three times unless the test was terminated prematurely for other reasons. Data collected in this study consisted of rectal temperature, skin temperature, heart rate, sweat production and evaporation, metabolic data, and subjective evaluations of thermal comfort and perceived exertion.

The results indicated that wearing the EOD suit produces significant increases in thermal physiological strain over performing the same tasks in a standard station uniform. However, the liquid-cooled Exotemp® personal cooling system was very effective in reducing that strain during heat exposure. Rectal temperatures, heart rates and fluid losses (dehydration) were reduced back to values comparable to those when not wearing the EOD suit, while skin temperatures were actually lower with the cooling system than with only the station uniform. Subjective data corroborated the physiological results, with subjects indicating reduced perceived exertion levels and improved thermal comfort when wearing the liquid-cooled garment with the EOD suit. In contrast, the ribbed vest and air vest showed no significant benefits with the EOD suit.

It is concluded that the increase in thermal physiological strain resulting from wearing the EOD suit during EOD work in hot environments can effectively be minimised by use of the Exotemp® personal cooling system.

Glossary of Terms

DCIEM	Defence and Civil Institute of Environmental Medicine
RCMP	Royal Canadian Mounted Police
MT	Metropolitan Toronto
ETF	Emergency Task Force
YR	York Region
ERU	Emergency Response Unit
OPP	Ontario Provincial Police
CD	Chemical Defence
CF	Canadian Forces
group **A**	schedule group A; subjects 1—7
group **B**	schedule group B; subjects 9—12
YNG	young (<45 years) age group
OLD	old (≥45 years) age group
EOD	Explosive Ordnance Disposal
STD	standard station uniform
EOD	**STD** + EOD suit
LIQ	**STD** + **EOD** + Exotemp® liquid cooling system
RIB	**STD** + **EOD** + passive ribbed vest
AIR	**STD** + **EOD** + active air vest
rh	relative humidity
WBGT	wet bulb globe temperature
18L	environmental test condition: 18°C; 40% rh
34L	environmental test condition: 34°C; 40% rh
34H	environmental test condition: 34°C; 80% rh
T_{re}	rectal temperature
$T_{re\text{-}i}$	initial Tre
$T_{re\text{-}f}$	final Tre
ΔT_{re}	change in Tre over duration of exposure
HR	heart rate
ECG	electrocardiograph
MST	mean skin temperature
MST_i	initial MST
MST_f	final MST
ΔMST	change in MST over duration of exposure
FLOSS	fluid loss; change in nude weight
%DEHY	percent dehydration; FLOSS/nude weight*100
FEVAP	fluid evaporated; change in dressed weight
E/P	evaporative efficiency; FEVAP/FLOSS*100
VE	ventilation rate
VO_2	aerobic power measured as oxygen consumption rate
VO_{2max}	maximal aerobic power
BTPS	body temperature and pressure; saturated
STPD	standard temperature and pressure; dry

INTRODUCTION

Explosive Ordnance Disposal (EOD) is a hazardous task requiring personnel to wear highly specialised protective clothing. The protection is aimed primarily at preventing or reducing blast and fragmentation injuries and is achieved by incorporating armoured plates of Kevlar/polycarbonate into a thickly-padded 18-layer Kevlar garment. The head is protected with a heavily-padded helmet with integral blower/visor demist system. The entire ensemble weighs approximately 25 kg and presents a significant load for a man. In addition to raising metabolic heat production in the body through the extra weight being carried, the garment provides a substantial impediment to the dissipation of body heat, especially in a hot environment. Failure to dissipate adequate quantities of heat results in elevated body temperatures and other symptoms of thermal physiological strain. These in turn can lead to performance impairment, both physical and mental, as well as overt heat illnesses. The very nature of the EOD task precludes any unnecessary compromises in performance if the work is to be conducted safely, effectively, and efficiently.

Many of the options normally available for alleviating thermal stress on the body are not available during EOD work. For example, the work is normally conducted in a "field" setting where environmental conditions cannot be manipulated; removal of extra clothing to decrease insulation and reduction in metabolic heat production through reduced work rates are clearly not feasible; and even the body's normal thermoregulatory responses such as increased sweating may do little to enhance heat loss from the body through the heavy garments. Under such circumstances, other technologies such as personal cooling may be necessary to facilitate thermoregulation and maximise performance.

A variety of personal cooling systems have been developed and tested in recent years for specialised applications in both military and civilian occupations (1-5). Designs have included both liquid- and air-based systems, in partial or whole body coverage configurations, with either open- or closed-loop coolant paths. While some operate through a tether to a central coolant supply, others offer portability, although at a reduced operating time. Due to the nature of EOD work, only man-carried portable systems are practical in EOD circumstances. The Exotemp® BD-1 Pro-Kool Personal Cooling System is a man-portable closed-loop liquid-based system that is compatible with both the EOD suit and EOD tasks. A variation of this system was used with great success in Canadian Forces (CF) Sea King helicopters during the Persian Gulf Crisis of 1990-91. Another variation was evaluated and found beneficial for engineering space personnel wearing chemical defence (CD) garments aboard CF ships (6) as well as with hazardous materials handling suits (7).

The present study was conducted to examine the efficacy of various personal cooling systems in alleviating thermal strain in personnel wearing EOD suits during simulated EOD work under various environmental conditions. The technology of prime interest was the Exotemp® system mentioned above. For comparison, a second approach involved wearing a thickly-ribbed vest of hydrophylic nylon under the EOD suit, the idea being to create a space between the body and the suit for passive air circulation and sweat evaporation. A third technology extended the concept of air movement beneath the EOD suit by actively circulating ambient air between the body and the EOD suit using an air-cooled vest originally developed for military aircrew. A secondary objective of the study was to compare physiological responses of younger and older subjects to EOD work in the heat. The study was conducted at the request of the Royal Canadian Mounted Police (RCMP), Explosives Disposal Technology Branch, Ottawa, Ontario, Canada. The results are of direct relevance to the CF since CF-EOD personnel wear the same EOD suit.

METHODS

Subjects

A total of 11 male police officers familiar with the use of the EOD ensemble volunteered and gave their written informed consent to participate in the study. All subjects were fully informed of the details of the experimental procedures, the associated risks, and the physical discomforts they might experience. Prior to their being accepted, subjects were given a medical examination and a Bruce Protocol Cardiac Stress Test (including 12-lead ECG) at the DCIEM Central Medical Board to ensure that there were no medical contraindications to their participation in the study. All subjects underwent a 30-minute familiarisation exposure in the chamber to ensure that they were familiar with the environmental conditions and work protocol.

An attempt was made to recruit subjects in two age categories: eight subjects under 45 y of age (category **YNG**); and four subjects 45 y of age or older (category **OLD**). The purpose of this selection criterion was to enable an examination of the effects of age on thermophysiological responses to EOD work in the heat. Forty-five was chosen as the age criterion because it is midway between 35 and 55 y, and most police officers doing EOD work are fairly senior. There is also evidence in the literature that persons over the age of 45 y are less able to tolerate heat stress (8, 9). The intent was to conduct a fairly extensive series of tests with the younger subjects, but repeat only a selection of these tests with the older group for comparison.

Two groups of subjects (seven "young" and four "old") were recruited. However, due to difficulties with subject availability, the age separation between the recruited groups was not as wide nor as clear as desired. One of the seven "younger" subjects was, in fact, 45 y old. The distinction between groups thus became more a matter of scheduling than age *per se*; hence the use of the designations "schedule groups **A** and **B**" in addition to "age groups **YNG** and **OLD**".

Determination of Maximal Aerobic Power and Maximum Heart Rate

Maximal aerobic power (VO_2max) was determined for each subject using open circuit spirometry on a motor driven treadmill in conjunction with the Bruce Protocol Stress Test. VO_2max was defined as the highest oxygen consumption ($mL \cdot kg^{-1} \cdot min^{-1}$) attained during this test. The subject's maximum heart rate (HR) was defined as the highest HR recorded during the test and was subsequently used to establish one criterion for withdrawal from the chamber during the heat stress trials.

Experimental Design and Test Schedule

The experiment utilised a repeated measures design in which the seven subjects in scheduling group **A** wore four clothing ensembles under each of three environmental test conditions. The subjects were recruited in two teams of four and three members (regrettably, we could not recruit a fourth subject for the second team). The distinction between teams was that one of the four clothing ensembles differed between teams (Team 1 wore a ribbed vest while Team 2 wore an air vest; see below).

The teams were tested sequentially during a six week period, with each team experiencing one environmental condition per week for three consecutive weeks. Within teams, subjects were randomly assigned to one of four clothing sequences which they followed throughout the three environments. Subjects were tested twice each day with three hours of rest between exposures, on two days of the week with one day of rest between test days. This arrangement minimised both environmental effects carryover (i.e., acclimation) as well as the amount of time off work for each subject.

The four subjects in scheduling group **B** were tested during the seventh week of the study. They were treated identically to Team 1 except that they only experienced one environmental test condition. Table 1 shows the complete experimental design and test schedule.

Table 1. Experimental Design and Test Schedule

Temp/Hum	Week	Time	Day 1	Day 2	Day 3	Day 4
			S1/S2	S3/S4	S1/S2	S3/S4
18/40	1	am	STD/EOD	LIQ/RIB	RIB/STD	EOD/LIQ
		pm	EOD/LIQ	RIB/STD	LIQ/RIB	STD/EOD
34/40	2	am	STD/EOD	LIQ/RIB	RIB/STD	EOD/LIQ
		pm	EOD/LIQ	RIB/STD	LIQ/RIB	STD/EOD
34/80	3	am	STD/EOD	LIQ/RIB	RIB/STD	EOD/LIQ
		pm	EOD/LIQ	RIB/STD	LIQ/RIB	STD/EOD
			S5/S6	S7/S8	S5/S6	S7/S8
18/40	4	am	STD/EOD	LIQ/ - - -	AIR/STD	EOD/ - - -
		pm	EOD/LIQ	AIR/ - - -	LIQ/AIR	STD/ - - -
34/40	5	am	STD/EOD	LIQ/ - - -	AIR/STD	EOD/ - - -
		pm	EOD/LIQ	AIR/ - - -	LIQ/AIR	STD/ - - -
34/80	6	am	STD/EOD	LIQ/ - - -	AIR/STD	EOD/ - - -
		pm	EOD/LIQ	AIR/ - - -	LIQ/AIR	STD/ - - -
			S9/S10	S11/S12	S9/S10	S11/S12
34/40	7	am	STD/EOD	LIQ/RIB	RIB/STD	EOD/LIQ
		pm	EOD/LIQ	RIB/STD	LIQ/RIB	STD/EOD

Temp/Hum: Temperature (°C); Relative Humidity (%)

Subject Codes: S1–S4: Category YNG; Team 1
S5–S8: Category YNG; Team 2 (subject 8 never recruited)
S9–S12: Category OLD

Clothing Codes: STD: Standard station uniform
EOD: STD + Explosives Ordnance Disposal suit
LIQ: liquid cooled garment + STD + EOD suit
RIB: passive ribbed vest + STD + EOD suit
AIR: active air vest + STD + EOD suit

Clothing Ensembles

A total of 5 clothing ensembles were tested in this study. The first was standard station dress (**STD**) consisting of personal undershorts, wool socks, combat trousers, combat boots, and either a short-sleeved t-shirt for the 34°C exposures, or a long-sleeved turtle neck or shirt for the 18°C exposures. This clothing configuration was used to establish baseline physiological responses to the environmental temperatures and work loads of the protocol, and all other test clothing was worn in addition to this **STD** dress.

The second clothing ensemble was designated **EOD** and consisted of the appropriate (according to temperature) STD ensemble plus the Safeco Bomb Disposal Suit. This is a thickly-padded 18-layer quilted Kevlar suit with Kevlar/polycarbonate armoured breast and groin plates. The head is protected by a helmet with integral blower for visor demisting. For this study, the face shield was modified (i.e., cut away) so that a mouthpiece could be utilised for measurements of metabolic rate. The blower system was powered by an external power supply in place of the battery pack, and no communication system was used. The entire ensemble weighed in excess of 25 kg.

The third clothing ensemble was designated **LIQ** and consisted of the appropriate STD dress plus the Exotemp® BD-1 Pro-Kool Personal Cooling System worn beneath the EOD suit. The cooling system consists of Nomex undergarments (longjohns, turtle neck, and hood) to which plasticised PVC tubing has been sewn on the inner surface using overstitching. Ice water is circulated through the tubing from a 2-L plastic bottle reservoir in a nylon pouch attached to the thigh with velcro straps. The electric pump and its rechargeable battery are also contained in this pouch. The system is offered with either 2-speed or 5-speed pumps; in this study we used a 5-speed pump set to the middle speed position (except for the 18°C tests when slower speeds were sometimes used to avoid cold discomfort). The plastic bottle reservoirs are normally filled with crushed ice and water; however, earlier studies showed that the cooling duration could be increased by prefreezing about 1.8 L of water in a bottle into a solid block of ice. Just prior to use, the bottles were topped up with water, and body movements ensured adequate mixing of the water and the melting ice block. In this study, bottles were replaced every 35 minutes regardless of how much ice was left.

The remaining two clothing ensembles involved air cooing systems. The first of these, designated **RIB**, utilised a thickly-ribbed vest made of hydrophylic nylon (Ultra-Cool, by Debi Gioello) to create an air space beneath the EOD suit. The hypothesis was that body motions may "pump" ambient air through this space and help cool the body by evaporation of sweat. The hydrophylic property of the nylon should help spread the sweat over a larger area to enhance evaporation and comfort. The second system, designated **AIR**, utilised an air vest developed at DCIEM for fighter pilots. This vest normally uses an aircraft-mounted blower system to actively circulate cool air over the torso. In this experiment, the vest was connected to a man-portable AR-5 respirator/blower unit powered by an external power supply. Ambient air from the chamber was used in place of conditioned air to provide a direct comparison between passive (ensemble **RIB**) and active (ensemble **AIR**) air cooling. Both ensembles were worn beneath the appropriate STD ensemble and the EOD suit.

Environmental Conditions

Three environmental conditions were used in this study. Condition **18L** was an environment of 18°C dry-bulb temperature and 40% relative humidity (rh). This condition simulated a cool day where the EOD suit was not expected to cause any thermal stress problems. Condition **34L** (34°C; 40% rh) simulated a hot summer day with comfortable humidity, while condition **34H** involved the same temperature but with 80% relative humidity. A comparison of conditions **34L** and **34H** would give some indications of the extent to which sweat evaporation can cool the body with the various clothing ensembles (primarily with the EOD suit). The sequence of environmental conditions can be seen in Table 1.

Experimental Protocol

Subjects followed a 35-minute work/rest schedule in the environmental chamber. Upon entering, they walked on a motorised treadmill (Quinton Series 18-54) at 3.5 $km \cdot hr^{-1}$, 0% grade, for 10 minutes. They then moved to a lifting work station where they performed an unstacking/ carrying (distance=2.5 m)/ stacking task with weighted (15 kg) boxes for 10 minutes (4 moves per minute). Finally, they moved to a rest station where they removed their EOD helmets and jackets (if worn) and sat on folding chairs for 15 minutes. During the final three minutes of rest they again put on their helmets and jackets. The work/rest cycle was repeated three times, with the rest period being omitted after the third work period, for a total of 90 minutes of exposure in the chamber. These activities were chosen to simulate aspects of EOD work (walking; lifting, carrying and bending; resting) while being easy to implement inside the chamber. Subjects worked in pairs, and conflicts for work stations and metabolic rate equipment were avoided by staggering the start times by 25 minutes.

Subject Preparations and Data Collection

Prior to each exposure, subjects gave a micropipet of blood from a finger prick for immediate analysis of hematocrit (Autocrit Ultra-3 Centrifuge) and sodium, potassium and chloride ion concentrations (Ciba-Corning 644 ISE Analyser). These data were a simple check on the state of hydration and electrolyte balance to ensure "normal physiology" for the second test exposure of the day.

Subjects began the dressing sequence by inserting a thermistor (Pharmaseal APC 400 Series) approximately 12 cm beyond the anal sphincter for measurement of rectal temperature (T_{re}). A nude weight was then obtained on an Electroscale Model 921 electronic scale with a resolution of 0.01 kg. Series 44004 thermistors (Yellow Springs Instruments) were taped to the skin with Transpore tape (3M Corporation) at the following 12 sites: forehead, chest, upper back, abdomen, lower back, front thigh, rear thigh, calf, shin, foot, forearm and wrist. A Polar-Electro Sport Tester PE3000 heart rate transmitter was strapped to each subject's chest and the receiver unit was later taped to the subject's clothing to give a continuous readout of HR in the chamber. Readings from this receiver were recorded manually at 5-minute intervals. HR was also stored at one minute intervals in the memory of the receiver for backup. In addition, a single lead ECG telemetry system (Siemens Telecust 354 U, 355 U) was used to continuously display HR outside the chamber.

Once instrumented, subjects donned the appropriate clothing ensembles as per the schedule. A fully-dressed weight was obtained just before entering the chamber. Inside, subjects followed the work/rest schedule described above. Metabolic gases were collected during the final four minutes of each treadmill walk and rest interval for the analysis of minute ventilation (VE) and oxygen consumption rate (VO_2) on a metabolic cart (Beckman MMC Horizon System). Values were averaged over the last three minutes of each collection period following a one minute washout of the system. As pointed out earlier, the standard EOD face shields had been modified to accept the mouthpiece so that the helmet would not have to be removed for gas collection. Note that metabolic data could not be obtained during the lifting task due to the body movements involved in transporting boxes across the chamber.

Subjects were asked to rate their levels of perceived exertion and thermal comfort at the midway point of the walk and rest intervals of each session. Comfort was rated on a 13-point scale ranging from 'so cold I am helpless' to 'so hot I am sick and nauseated' (numerical scores of 1 – 13), while perceived exertion was rated on a 13-point scale ranging from 'nothing at all' to 'maximal' (numerical scores 0 – 12). Subjects were permitted to report half-point scores.

Subjects were not allowed any fluid intake after the initial nude weight. They were, however, encouraged to drink prior to this measurement for any hot chamber exposures to help reduce dehydration. A fully-dressed post-exposure weight was obtained immediately following exit from the chamber, and another nude weight was obtained immediately after the undressing procedure. The subjects were given cool water following the final nude weighing to replenish lost fluids.

The majority of data was collected with a Hewlett-Packard data acquisition system (HP3497A control unit, HP9836 computer, HP2934A printer) which printed, graphed, and stored one-minute averages of data each minute. Thermistors for measurements of skin and core temperature were connected directly to this system. Environmental conditions within the chamber were continuously monitored via an electronic WBGT meter (Reuter-Stokes RSS-220 Heat Stress Monitor) also connected to the data acquisition system.

Criteria for withdrawal of the subjects from the chamber were: elapsed time of 90 minutes; T_{re} reaching 39.0°C; T_{re} rising 2°C above the initial reading; HR reaching 95% of maximum for at least three minutes; or the subject choosing to terminate the exposure due to fatigue, dizziness, nausea, excessive discomfort, etc.

Data Reduction

Mean skin temperature (MST) was calculated as the area-weighted average of the 12 skin temperatures (Livingstone *et al*, 1983). Rectal and skin temperature data were reduced to initial values, final values, and changes over the duration of the exposure. Fluid loss (FLOSS) was calculated as the difference between pre- and post-exposure nude weights. It represents the sweat produced by the body and when expressed as a percentage of initial nude weight is indicative of the level of dehydration (%DEHY). The difference between pre- and post-exposure dressed weights represents fluid evaporated (FEVAP) from the man/clothing system. This value is heavily dependent upon the composition, form, and fit of the garments as well as body movements, activities (e.g., removing the EOD suit and helmet during rest), and environmental conditions (i.e., it depends on the "functional" clothing system). The ratio of sweat evaporated to sweat produced (E/P) is called the evaporative efficiency of the clothing system under the specific test conditions and is presented here as a percentage.

The 5-minute manual recordings of heart rate (HR) were combined to yield averages over each work/rest interval (two readings averaged during walking and lifting activities, three readings averaged during rest periods). These data, along with the metabolic and subjective parameters, were analysed over time as a function of activity.

Statistical Analyses

All statistical analyses were performed on a Macintosh computer using Statview II and SuperAnova software (Abacus Concepts). The evaluation of the Exotemp® personal cooling system in conjunction with the EOD suit was done via a 2-way analysis of variance with repeated measures using the seven subjects of schedule group **A**. Comparisons were made between clothing ensembles **STD**, **EOD**, and **LIQ** (factor 1) and environmental conditions **18L**, **34L**, and **34H** (factor 2) for those parameters not analysed serially over time (body temperatures, body weights, etc.). For the parameters where time was of interest (HR, metabolic data, subjective data, etc.), "time" was used as factor 2 and separate analyses were carried out for each environmental condition. Linear means comparison contrasts were used to compare means within significant main effects and interactions (i.e., post-hoc tests).

Repeated measures analyses could not be used to compare the **LIQ**, **RIB** and **AIR** cooling ensembles simultaneously because not all subjects wore each system. Analysis procedures for these comparisons are outlined in the Results section.

Comparisons between age groups **YNG** and **OLD** (under condition **34L** only) were carried out using a 1-within (age) / 1-between (clothing) factor repeated measures analysis with clothing ensembles **STD**, **EOD**, and **LIQ**.

Unless stated otherwise, all results are presented as means ± standard errors, and results were considered significant at $p \leq 0.05$. To assist in demonstrating the relative significance of various factors, p-values are presented to 4 decimal places as obtained on the computer printouts.

RESULTS and DISCUSSION

Subject Sample Characteristics

It should be pointed out immediately that recruitment of subjects for this trial was difficult. The intent had been to use only bomb squad personnel from the ranks of the Ottawa RCMP. However, insufficient numbers of younger officers familiar with EOD work were available from that force. In addition, four potential subjects were rejected during the cardiac stress tests for medical considerations. Due to time and money constraints, replacement subjects were obtained locally from the Metropolitan Toronto Emergency Task Force (MT ETF), York Regional Police Emergency Response Unit (YR ERU), and the Ontario Provincial Police (OPP). This process resulted in a subject sample with the characteristics shown in Table 2.

Note that Table 2 provides summary data for the subjects in schedule group **A** (i.e., subjects 1 - 7; bottom of Table) as well as for subjects in age groups **YNG** and **OLD**. A comparison of the age ranges and standard deviations for age group **YNG** and schedule group **A** shows that treating subject #7 as part of the **OLD** group results in a "tighter" **YNG** group with respect to age (i.e., a smaller standard deviation). Although not shown in Table 2, the standard deviation of age group **OLD** is also reduced slightly by including subject #7 in this group. Based on these findings, subject #7 was included in group **OLD** for any age-related analyses, but was included in schedule group **A** for the primary clothing analyses in order to maximise the sample size.

Student's one-tailed t-test indicated a statistically significant difference ($p=0.0001$) in age between groups **YNG** and **OLD**. However, neither maximum HR nor VO_2max differed significantly between the groups ($p=0.2367$ and $p=0.4243$, respectively). Assuming that physiology rather than age *per se* determines the body's response to stress, the latter results provide assurance that the inclusion of subject #7 into schedule group **A** did not unduly bias the

Table 2. Subject Characteristics

Age Group	Subj. No. (ref: Table 1)	Age (y)	Height (cm)	Weight (kg)	------ Maximum Values HR (bpm)	VE (L/min)	VO2 (L/min)	--------- VO2 (mL/kg/min)	Force
YNG	1	38	175	72	179	125	3.57	49.7	MT ETF
	2	40	178	77	184	126	3.69	48.0	MT ETF
	3	41	185	93	196	140	3.23	34.8	RCMP
	4	42	178	80	179	87	2.20	27.5	RCMP
	5	41	183	95	184	124	4.17	43.9	MT ETF
	6	38	183	79	170	173	5.79	74.2	YR ERU
	Mean	40.0	180.3	82.7	182.0	129.2	3.8	46.3	
	Std. Dev.	1.7	3.9	9.2	8.6	27.8	1.2	16.0	
OLD	7	45	178	70	204	120	2.74	39.1	RCMP
	9	45	183	88	187	91	2.34	26.6	OPP
	10	45	183	84	177	166	4.10	48.8	MT ETF
	11	45	178	76	190	113	3.02	39.7	RCMP
	12	48	180	83	187	124	3.67	44.2	RCMP
	Mean	45.6	180.4	80.2	189.0	122.8	3.2	39.7	
	Std. Dev.	1.3	2.5	7.2	9.7	27.3	0.7	8.3	
Schedule Group A (Subjects 1 - 7)	Mean	40.7	180.0	80.9	185.1	127.9	3.63	45.3	
	Std.Dev.	2.4	3.7	9.7	11.4	25.6	1.15	14.9	

results. Further analyses (Kruskal-Wallis test; $p=0.0074$) showed that VO_2max, but not maximum HR, did depend on what police force the subjects were from. Apparently, ETF/ERU officers are strongly encouraged to put considerable time and effort into physical training, and the benefits of that training with regard to aerobic fitness (VO_2max) are clearly visible in Table 2.

Blood Analyses: Na^+, K^+, Cl^-, Hematocrit

The finger prick blood samples taken prior to each test exposure were analysed immediately to ensure that subjects were not beginning an exposure with abnormal blood chemistry such as may arise by excessive fluid loss during a previous (i.e., morning) exposure in the chamber. No abnormalities were found, and all subjects were able to adhere to the two-run-per-day test schedule. No further analyses were carried out on these data.

STD / EOD / LIQ Comparisons: Schedule Group A

Tolerance time

All seven subjects of schedule group **A** completed the full 90-minute protocol in each clothing configuration and environmental condition except for condition **34H** when wearing the EOD suit. Under this condition, five of the seven failed to go the full duration. Since the only difference between conditions **EOD-34L** and **EOD-34H** was an increase in humidity, these results suggest that working in the EOD suit (without the liquid cooling garment) will produce greater physiological strain when relative humidity is high. Viewed differently, the results suggest that perhaps evaporation of sweat, which should be higher at low humidities, is important in the relief of thermal stress. Evaporative cooling in the various ensembles is addressed in more detail below.

The mean tolerance time for **EOD-34H** was 81.0±4.7 minutes, with the shortest time being 55 minutes. Two subjects were removed for exceeding core temperature cutoff criteria, one was removed due to high heart rate, another was removed when he showed signs of excessive heat strain (stumbling, incoherence, nausea), and one requested to be removed due to excessive discomfort (simply too hot and too tired to continue). These results indicate that the environmental test conditions were indeed severe enough to demonstrate not only the desirability of, but also the necessity for, personal cooling garments with the EOD suit.

Rectal Temperature Responses

Initial rectal temperature ($T_{re\text{-}i}$) was examined to ensure that core temperature responses across the various test conditions were not biased by different starting temperatures. Twenty-one pairs of data were available in which subjects did both morning and afternoon tests in the relevant clothing ensembles. Mean $T_{re\text{-}i}$ in the afternoon (37.33±0.07) was significantly warmer than in the morning (37.14±0.09°C) for these subjects ($p=0.0006$; Student's one-tailed paired t-test) by a small amount. This could be a reflection of circadian temperature effects and/or some residual temperature elevation from the morning experiments. However, $T_{re\text{-}i}$ showed no statistically significant difference across any of the trials as a function of clothing ($p=0.5471$), environment ($p=0.1304$), or the interaction of the two factors ($p=0.5509$). This demonstrates the effectiveness of the permuted clothing sequence of the experimental design in controlling for the variations in $T_{re\text{-}i}$. Mean $T_{re\text{-}i}$ across all trials was 37.24±0.05°C.

Mean final rectal temperatures ($T_{re\text{-}f}$) are shown in the upper panel of Figure 1 for the nine test conditions being considered in this section. Statistical analyses showed highly significant main effects of both clothing ($p=0.0001$) and environmental condition ($p=0.0005$) but no significant interaction between the two factors ($p=0.0807$). Thus, the effects of clothing were similar under all three environmental conditions. At each environmental condition, $T_{re\text{-}f}$ was highest when wearing ensemble **EOD**. $T_{re\text{-}f}$ increased slightly with increasing thermal stress of the environment even with ensemble **STD** (37.40°C to 37.70°C from **18L** to **34H**) but not nearly as much as with ensemble **EOD** (37.72°C to

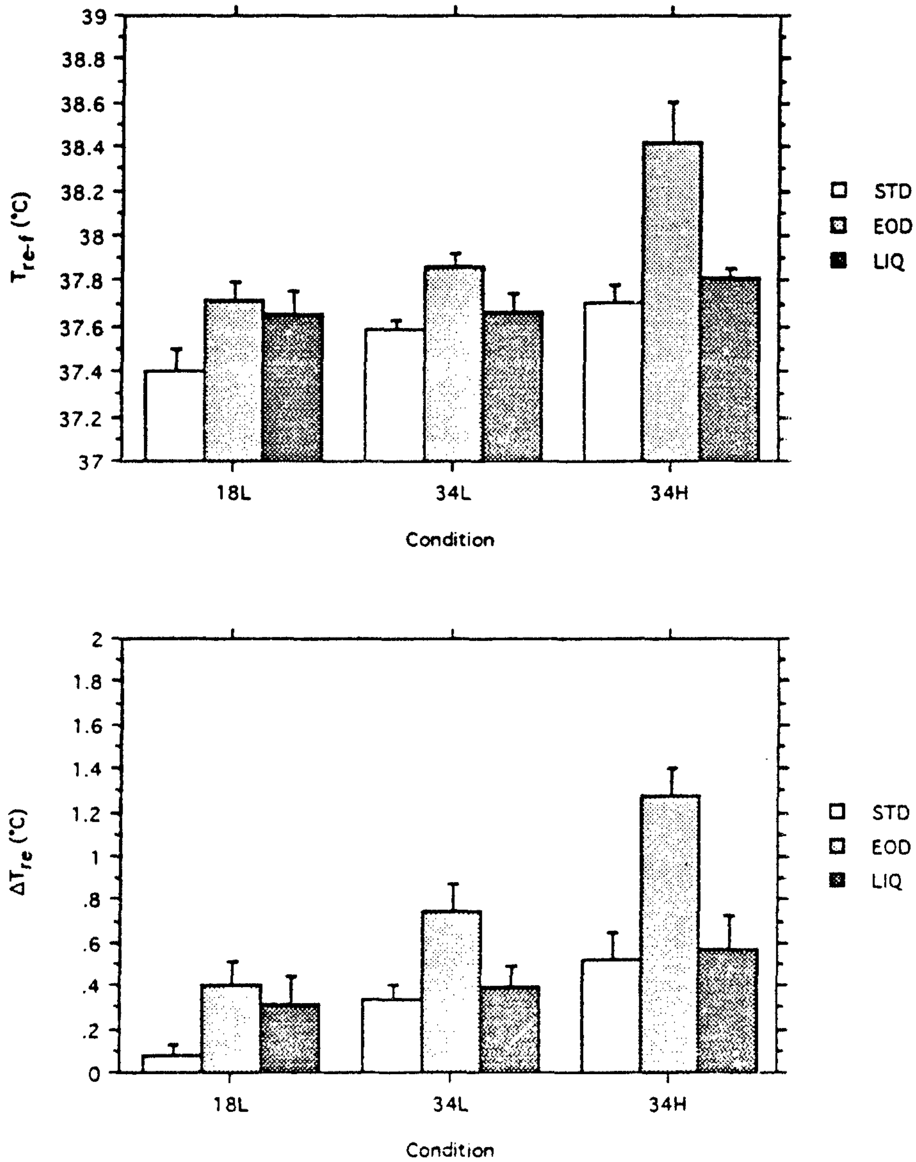


Figure 1. Mean final rectal temperature ($T_{re\text{-}f}$; upper panel) and mean change in rectal temperature (ΔT_{re}; lower panel) as a function of Condition for the three clothing ensembles.

38.42°C from **18L** to **34H**). (Note: numerical data for many of the results presented graphically are tabulated in Tables A1 – A3 for easy reference.)

The benefit of the Exotemp® liquid cooling garment in keeping $T_{re\text{-}f}$ low is clearly evident in Fig. 1, particularly under condition **34H** $T_{re\text{-}f}$ was actually quite constant with the **LIQ** ensemble, ranging only from 37.66°C to 37.81°C across the three environmental conditions. The differences between **STD** and **LIQ** at both **34L** and **34H** are, in fact, not statistically significant ($p \geq 0.29$), showing that the liquid cooling garment reduces the thermal strain in the EOD suit to levels comparable to those when not wearing the EOD suit at all.

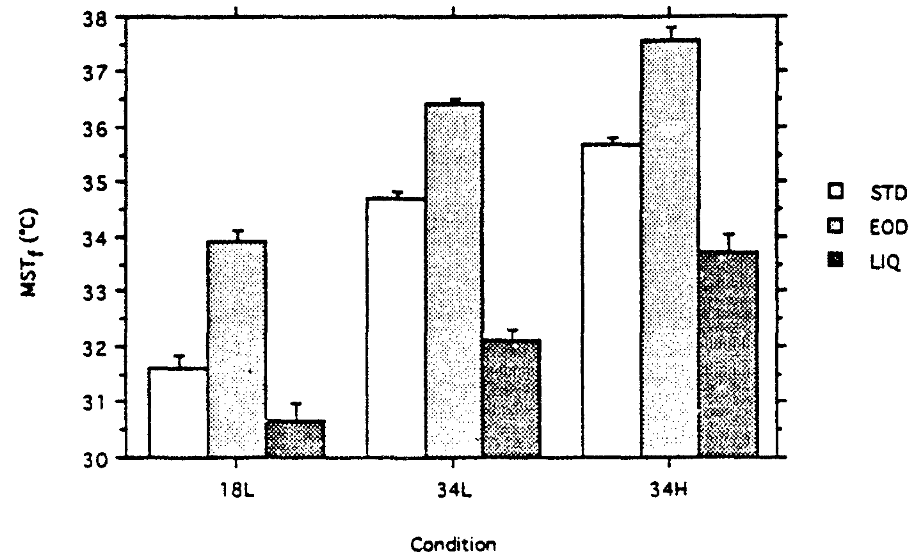
The mean value of $T_{re\text{-}f}$ during **EOD-34H** was 38.42±0.18°C, and one subject reached 39.11°C before being removed from the chamber. These levels of deep body temperature are well above the 37.6°C threshold considered by some to be the onset of mental impairment during thermal stress (10, 11). The present study did not test mental performance specifically, and the physical tasks performed by the subjects did not require the mental skills and concentration that true EOD work would likely entail. Certainly, the element of danger normally present in EOD work and its consequent emotional strain were absent in this study. No conclusions can be drawn, therefore, about deep body temperature and mental impairment. However, the fact that five of the seven subjects were unable to complete the protocol under test condition **EOD-34H** suggests that a rectal temperature of about 38.5°C may be a reasonable physiological tolerance limit for the physical aspects of EOD work.

The effects of variations in $T_{re\text{-}i}$ on rectal temperature responses can be accounted for to some extent by examining individual subjects' changes in rectal temperature (ΔT_{re}) over the duration of an exposure. This approach sometimes also enhances the discrimination between treatments/conditions over that obtained from considerations of $T_{re\text{-}f}$ alone. The nine mean ΔT_{re} values obtained in this study are shown in the lower panel of Fig. 1. Because of the relative constancy of the $T_{re\text{-}i}$ data in this study, the ΔT_{re} data add little new insight. Both clothing ensemble (p=0.0007) and environmental condition (p=0.0001) showed statistically significant main effects as well as a now slightly significant interaction (p=0.0377). The major change from the T_{re-f} results is that the difference in ΔT_{re} between **EOD-34L** and **LIQ-34L** is now also significant (p=0.0168), whereas the T_{re-f} analyses indicated significant differences (p=0.0025) between the **EOD** and **LIQ** ensembles only under condition **34H** (note that **EOD** – **LIQ** differences at **18L** were not significantly different for either T_{re-f} or ΔT_{re}). This shows that the Exotemp® cooling system is effective in reducing the rise in T_{re} in a hot environment even at moderate relative humidity.

Mean Skin Temperature Responses

Initial mean skin temperature (MST_i) was also analysed to ensure that there were no large variations in this parameter prior to commencement of the test exposures. As with T_{re-i}, there were no statistically significant differences in this parameter throughout any of the test conditions. The largest variation occurred between the **STD** and **LIQ** clothing ensembles during the **18L** evaluations, but it amounted to less than 1°C. The overall grand mean MST_i was 32.42±0.09°C, which is very near the 33°C generally accepted as the mean skin temperature of the human at thermoneutrality (12). The importance of this finding is again that all tests in this study, particularly those conducted in the afternoon, began with no undue thermal strain in the subjects.

Final mean skin temperature (MST_f) showed highly significant main effects for clothing and condition (p=0.0001 for both factors) as well as a significant interaction between clothing and condition (p=0.0051). The MST_f data are shown in the upper panel of Figure 2 for the nine relevant test conditions. The most striking feature of Fig. 2 is that MST_f was consistently lowest at all three environmental conditions whenever clothing ensemble **LIQ** was worn. In fact, MST_f was even cooler in ensemble **LIQ** than in ensemble **STD**. This is actually not surprising, since the cooling garment does circulate cool water over the skin. The small (~3°C) rise in MST_f with increasing environmental stress (condition **18L** to **34H**) when wearing ensemble **LIQ** is probably a direct result



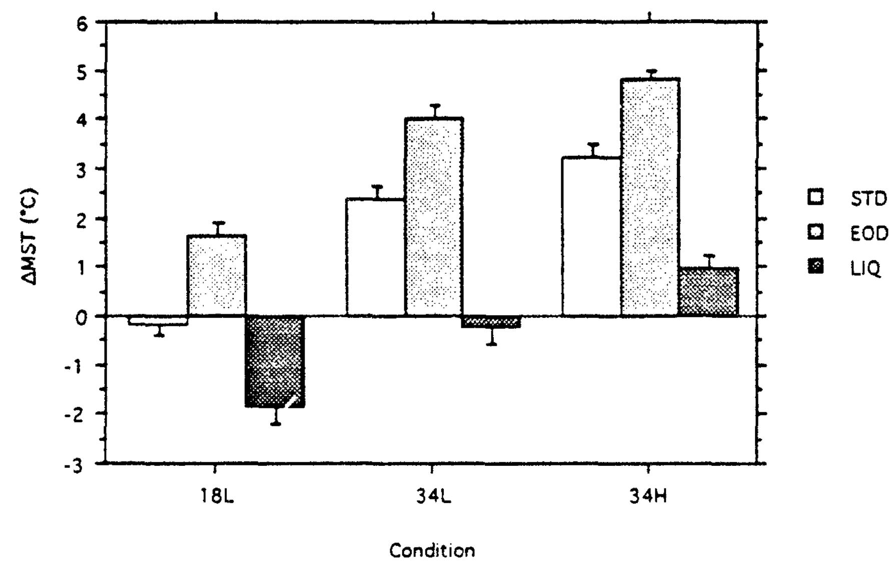


Figure 2. Mean final mean skin temperature (MST_f; upper panel) and mean change in mean skin temperature (ΔMST; lower panel) as a function of Condition for the three clothing ensembles.

of not allowing subjects to vary the speed of the water circulation pump, hence keeping the heat removal rate fairly constant throughout the study. One would speculate that a reduction in pump speed during condition **18L** and an increase in speed during condition **34H** may have "levelled out" MST_f across the three environmental conditions.

The highest mean MST_f of 37.58±0.21°C was obtained during condition **EOD-34H.** This is only 0.34°C below the mean $T_{re\text{-}f}$ obtained during the same test condition. A convergence of mean skin and deep body temperatures has been cited as one criterion for termination of heat stress exposure (13). Considering that five of the seven subjects could not complete the 90-minute test under this condition, these results are consistent with that criterion.

The data for change in mean skin temperature (ΔMST) are presented in the lower panel of Fig. 2. Having shown that subjects began the exposures with thermoneutral (i.e., "comfortable") skin temperatures, the overcooling of the skin during condition **18L** (i.e., a negative ΔMST) and the undercooling at **34H** (i.e., a positive ΔMST) due to the use of a fixed pump speed are very evident. Also, as amply demonstrated in previous figures, thermal strain as measured here by ΔMST tends to increase with increasing thermal stress in all clothing ensembles, with maximum thermal strain being associated with the **EOD** ensemble. Both clothing and condition were statistically significant factors in ΔMST ($p=0.0001$) and there was no interaction between them.

Body Weight Changes

The body weight change data obtained in this study are of variable quality. Of the four weight parameters, the changes in nude weight representing fluid loss (FLOSS) and the derived parameter percent dehydration (%DEHY) are probably the more reliable. By comparison, the changes in dressed weight representing fluid evaporated (FEVAP) and the derived quantity evaporative efficiency (E/P) are prone to considerable error that is difficult to control for. In particular, clothing elements can exchange moisture with their surroundings between weighings as subjects move from dressing area to chamber and back again. The amount of moisture exchanged with an environment depends on time, temperature, relative humidity, air movement, body movement, fabric affinity for moisture, etc. In addition, the liquid cooling garment can have different quantities of liquid in its tubing before and after use as bottles are exchanged (this was accounted for in this study), and the cold fluid can induce ambient moisture condensation into the clothing in humid environments. Finally, unknown amounts of fluid leakage did occur occasionally during bottle changes with the cooling garment, sometimes dripping on the floor and other times wetting the clothing. Having raised these reservations and cautions, all four weight parameters obtained in this study are now presented.

The upper panel of Figure 3 presents the FLOSS data as a function of environmental condition for the three clothing ensembles. Note that fluid losses from the body increased progressively for all three ensembles as the environmental stress increased from **18L** to **34H**. Under each condition, fluid losses were greatest in ensemble **EOD**, with the maximum mean loss exceeding 1.5 kg under condition **34H**. The highest fluid loss observed for an individual subject was 2.82 kg, and it may be noteworthy that this was from the fittest subject in the study.

Statistically, both clothing ($p=0.0038$) and condition ($p=0.0011$) were significant main effects, and there was a marginally significant interaction ($p=0.0462$). Neglecting this interaction, there was no statistically significant difference in FLOSS between ensembles **STD** and **LIQ** averaged across all environmental conditions ($p=0.5240$), showing the significant benefit of the liquid cooling suit in reducing fluid losses to levels comparable to those when not wearing the EOD suit. Mean fluid losses in ensemble **LIQ** were less than 50% of the values in ensemble **EOD** under each environmental condition. Averaged across all conditions, ensemble **EOD** was significantly different from both **STD** ($p=0.0024$) and **LIQ** ($p=0.0037$). The lower panel presents essentially the same information but expressed as %DEHY. The highest mean dehydration

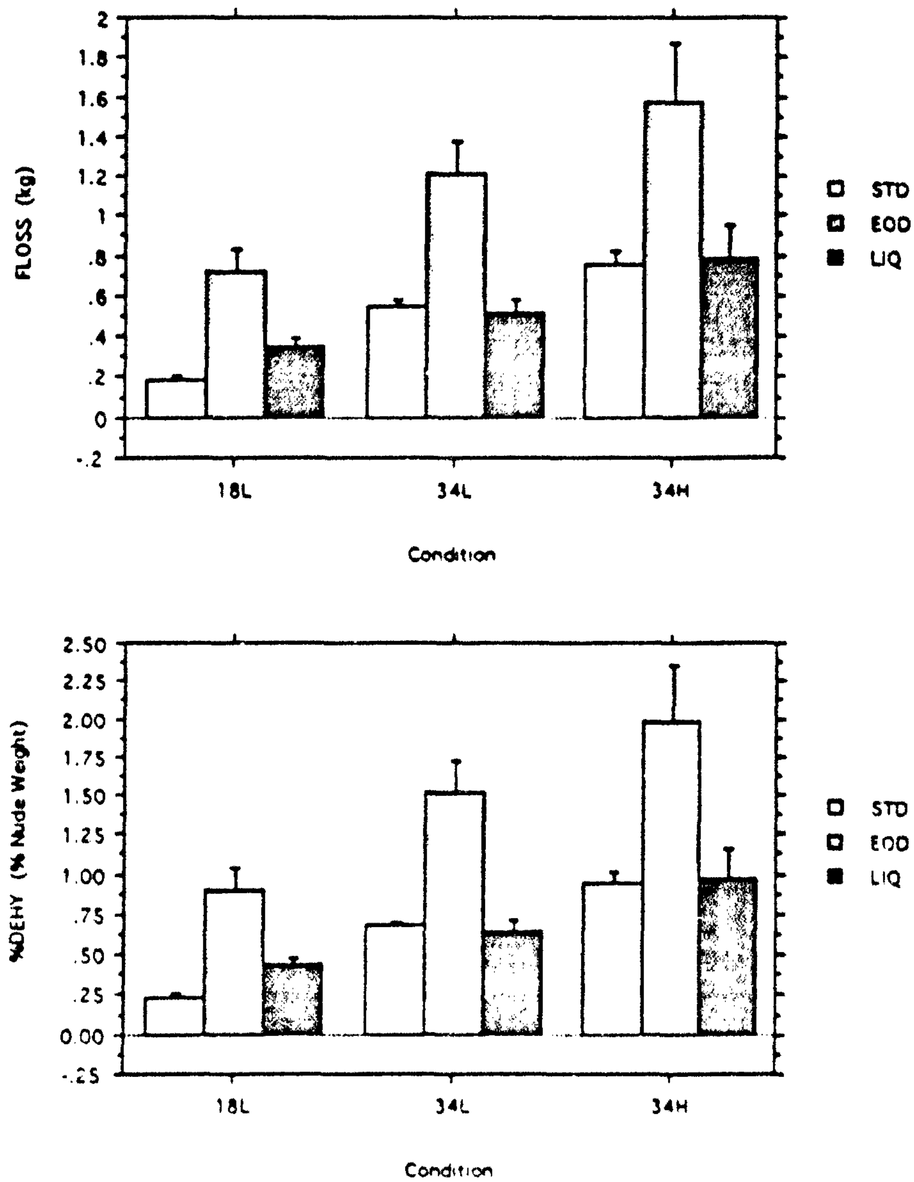


Figure 3. Fluid loss (FLOSS; upper panel) and percent dehydration (%DEHY; lower panel) as a function of Condition for the three clothing ensembles

level of 1.98% was obtained with ensemble **EOD** under condition **34H**. Note that dehydration by 2% of initial body weight is associated with a very strong thirst sensation, and that dehydration with ensemble **LIQ** never exceeded 1%.

Figure 4 presents the FEVAP and E/P data in the upper and lower panels, respectively. As pointed out, these data are somewhat suspect due to uncontrollable factors related to the protocol, so minor differences in results should not be emphasised strongly. There are, however, some interesting patterns of larger differences in the data that can be addressed.

First, the FEVAP data show that considerably more fluid evaporated from the man/clothing system under condition **34L** than under condition **34H**. This is consistent with the laws of physics and the expectation that a lower relative humidity at the same ambient temperature should facilitate evaporation of moisture from the body. This evaporative cooling should, in theory, provide some relief of thermal strain in the body. Both the rectal temperature and skin temperature data in Figs. 1 and 2 showed that thermal strain was indeed higher under condition **34H** than under condition **34L**. The results are, therefore, consistent. Note, however, that the FEVAP data should not be used to calculate latent heat removal from the body since the EOD jacket and helmet were removed during the rest periods. Any sweat from the subject that wetted the inner layers of the EOD jacket and subsequently evaporated during the rest period would not be removing heat from the body.

The second interesting observation is that the average FEVAP was negative with ensemble **LIQ** under condition **34H**. A negative evaporation rate represents a gain in weight by the man/clothing system, and the most likely cause would be condensation of ambient moisture by the cold fluid circulating through the cooling garment. This idea is supported by the fact that the weight gain occurred under the 80% relative humidity condition but not when relative humidity was 40%. Since the individual clothing elements were not weighed independently it is not possible to determine in which clothing layer the

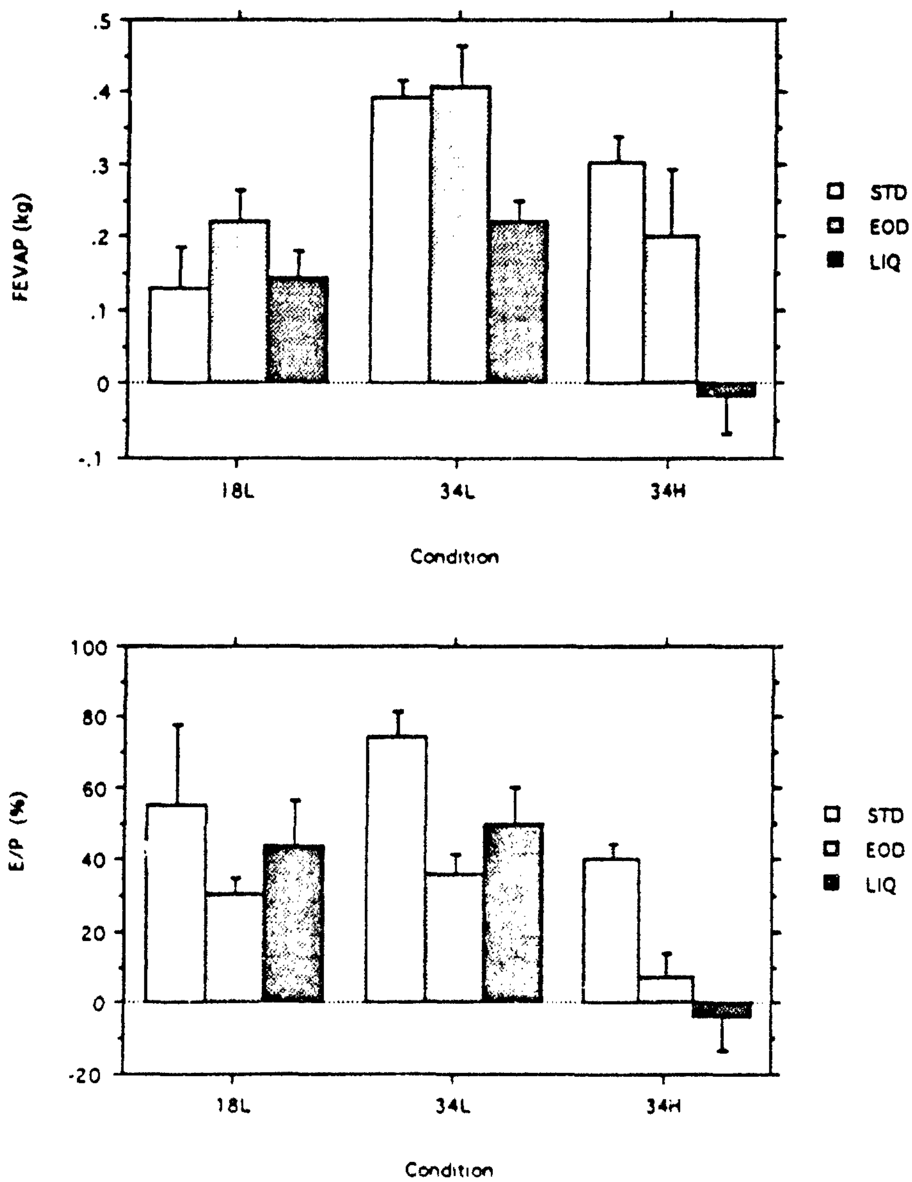


Figure 4. Fluid evaporated (FEVAP; upper panel) and evaporative efficiency (E/P; lower panel) as a function of Condition for the three clothing ensembles.

condensed moisture accumulated most. However, given that subjects did remove the EOD jacket and helmet during the rest periods, thereby exposing the cooling garment to the chamber air, much of the condensation could have been into the liquid cooling garment itself.

The E/P data in the lower panel of Fig. 4 are only as reliable as the FEVAP data upon which E/P is based, and evaporation from the inner surface of the garment has already been addressed. Still, there are clear indications that the EOD suit reduces the evaporative efficiency compared with standard clothing. Statistically, ensemble **STD** was significantly different from ensembles **EOD** ($p=0.0135$) and **LIQ** ($p=0.0255$), both of which involved wearing the EOD suit, while **EOD** and **LIQ** were not significantly different from each other ($p=0.4614$). Note that ensemble **LIQ** had a higher E/P compared to ensemble **EOD** under conditions **18L** and **34L** (despite lower FEVAP values), but a lower (in fact, a negative) E/P under condition **34H**. The increases in E/P are probably due to the decreases in FLOSS, while the negative value is undoubtedly an artifact due to condensation of moisture into the clothing system.

Heart Rate Responses

To make the HR analyses and data presentations more manageable, results for the three environmental conditions have been separated. This approach has a further benefit in that the statistical analyses for conditions **18L** and **34L** can be based on seven subjects since everyone completed the full 90 minutes under these conditions. Three subjects failed to complete the third lifting task during condition **34H**, so the HR data during this condition are limited to four subjects.

Figure 5 shows the mean HR responses as functions of clothing and activity during all three environmental conditions. As a general comment on the three data panels, the elevations in HR during periods of physical work (walking, lifting) compared to rest periods are clearly visible. Considering first the upper panel representing condition **18L**, HR was significantly elevated in ensembles **EOD** and **LIQ** compared to ensemble **STD** ($p=0.0001$ in both cases), probably

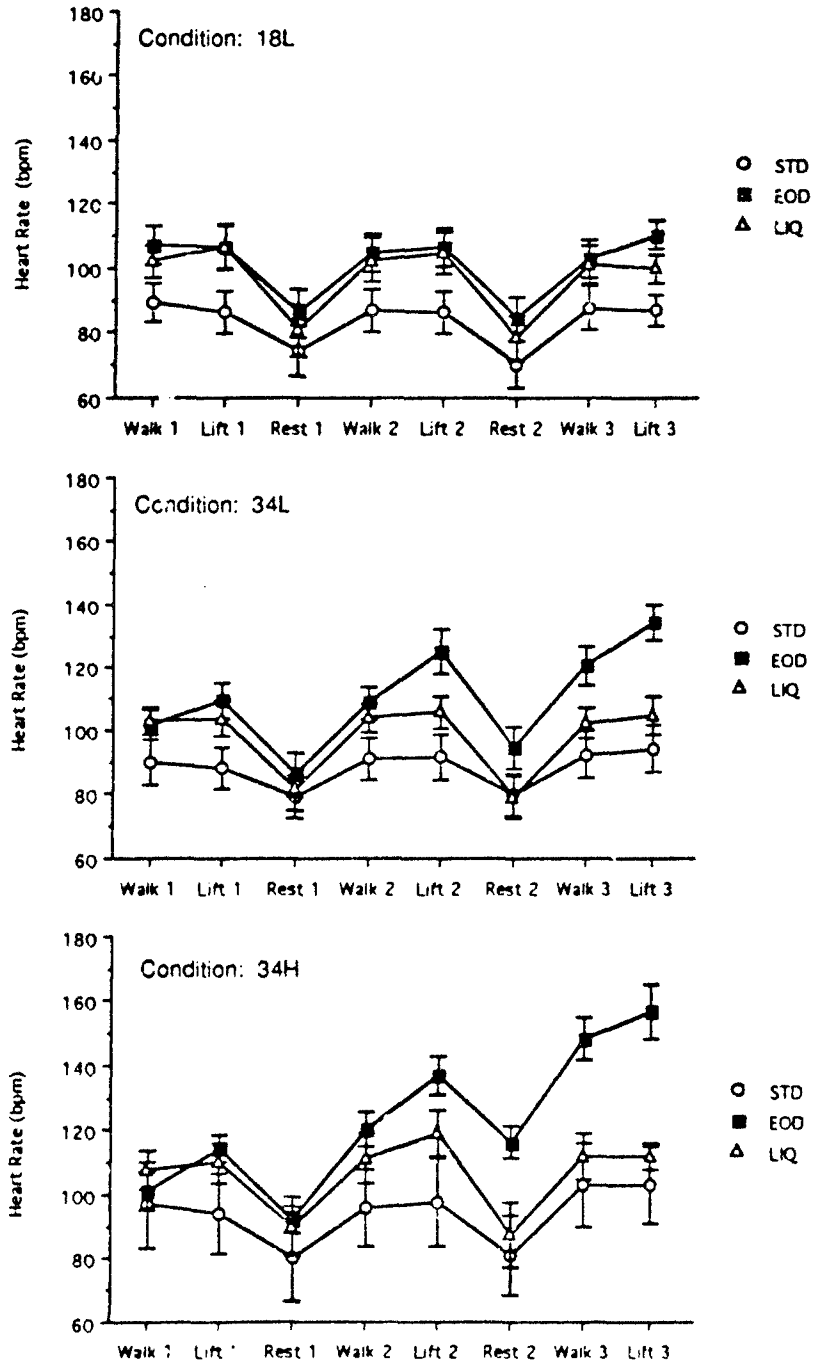


Figure 5. Mean heart rate as a function of activity for three clothing ensembles and three environmental conditions.

due to the extra effort required to carry the weight of the EOD suit. However, the mean HR for the seven subjects never exceeded 110 bpm in any clothing ensemble, showing that the activities themselves in the absence of environmental thermal stress did not involve hard physical work. In fact, mean HR never even reached 90 bpm in ensemble **STD**. There was no statistically significant interaction between clothing and time under condition **18L**.

The HR responses under conditions **34L** and **34H**, as shown in the middle and lower panels of Fig. 5, respectively, were quite different. The most obvious effect is that HR increased progressively over time for each specific activity (i.e., Walk 1 – Walk 3; Lift 1 – Lift 3) under both environmental conditions with ensemble **EOD**, to the point that HR even during the second rest period was higher than during the first (94.7 vs 86.0 bpm, 116.3 vs 92.3 bpm; Rest 2 vs Rest 1 during **EOD-34L** and **EOD-34H**, respectively). In contrast, HR response with ensembles **STD** and **LIQ** was much more stable over time, with little difference between the two rest periods of any given exposure. This shows that the thermal physiological strain of working in a hot environment with the EOD suit (without cooling) is cumulative if insufficient rest time is provided to allow this strain to be dissipated. By comparison, use of the **LIQ** ensemble reduces strain sufficiently during the work periods so that there is no residual cardiac strain (*vis-a-vis* elevated HR) during the rest periods.

The highest mean HR of 156.6±8.2 bpm (n=4) was recorded during the final lifting activity of condition **34H** when wearing ensemble **EOD**. This value is 84.4% of the average maximum HR (185.5 bpm) of the four subjects for whom data were available during Lift 3, and it indicates the presence of a significant load on the heart. While it is not possible to accurately separate the effects of work and temperature, comparison with **EOD-18L** (where heat stress was presumably not a factor) suggests that most of the stress on the heart during **EOD-34H** was thermally derived (massive vasodilation and high cardiac output to dissipate heat through the skin are normal physiological consequences of thermal strain).

A comparison of the three panels in Fig. 5 indicates a small but noticeable increase in mean HR for all clothing ensembles (including **STD**) as a function of increasing stress of the environment. However, even under condition **34H**, the Exotemp® cooling system was able to keep mean HR below 120 bpm. This is less than a 10% increase over the maximum HR recorded during condition **18L** and it demonstrates the significant benefit of the cooling system in reducing thermal physiological strain. Statistically, all factors (clothing, time, and clothing-time interaction) with respect to HR were significant at $p=0.05$ under all conditions.

Metabolic Responses

The metabolic measurements were processed to arrive at ventilation rate (VE; $L \cdot min^{-1}$; BTPS) and oxygen consumption rate (VO_2; $L \cdot min^{-1}$; STPD). Further expression of the oxygen consumption rate per unit total weight of the man/clothing system ($mL \cdot kg^{-1} \cdot min^{-1}$) allowed for a check of metabolic efficiency. As with the HR data, results were analysed over time with separate analyses for the three environmental conditions. Note that because not all subjects were able to complete condition **34H**, the data for that condition are based on the five subjects who completed the final treadmill walk.

Figure 6 presents the VE data as a function of activity for the three clothing ensembles under the three environmental conditions. There is clearly a very strong time dependence in the data, with ventilation rates during periods of work rising to some 2–3 X the rates during periods of rest. VE under all environmental conditions was also significantly affected by the clothing being worn ($p=0.0001$), with ensemble **STD** giving the lowest values for all measurement periods.

During all three walk periods of condition **18L** and during the first and second walk periods of the warm conditions, VE was slightly higher with ensemble **LIQ** than with ensemble **EOD**. This might be a reflection of the extra weight of the

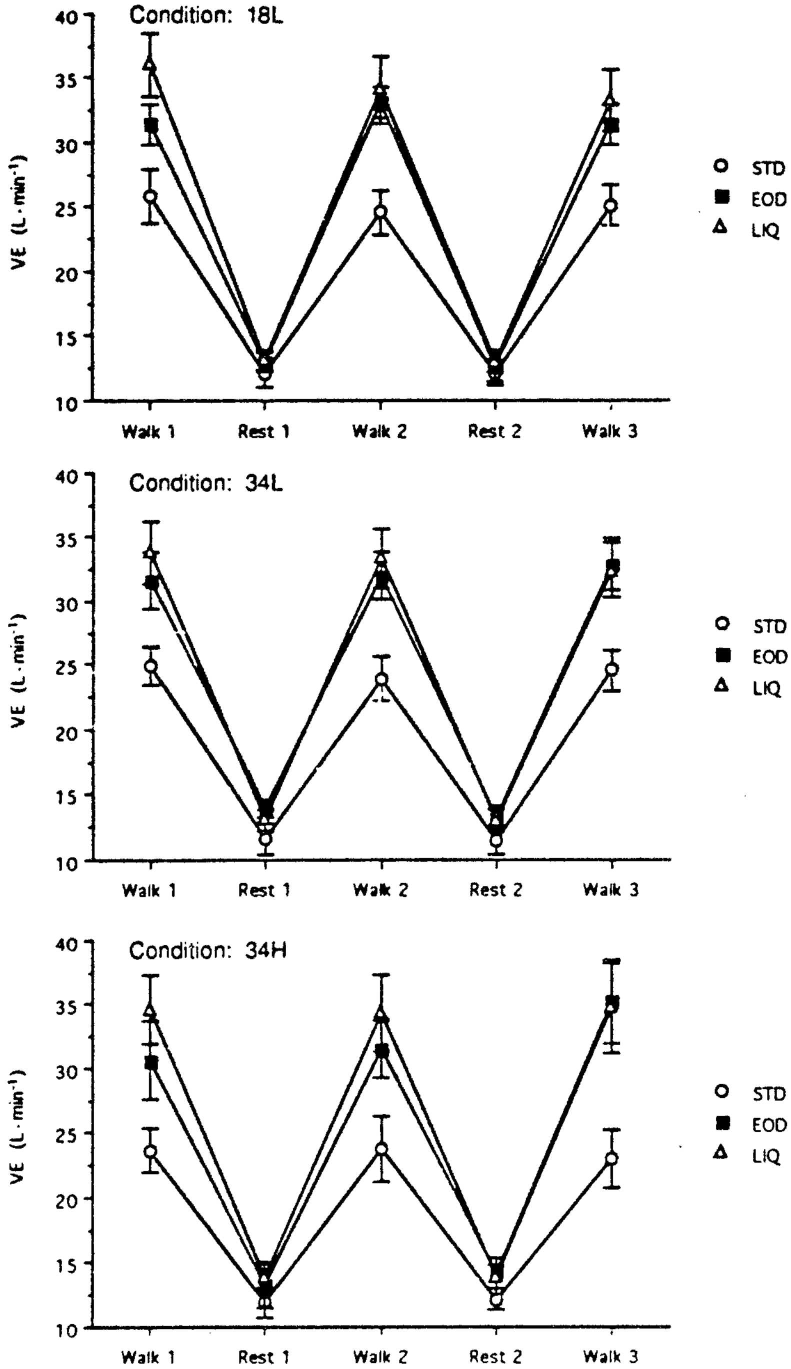


Figure 6. Mean ventilation (VE) as a function of activity for three clothing ensembles and three environmental conditions.

cooling equipment being carried (typically 3.9 kg). However, during the third walk period under the warm conditions, VE was essentially the same with ensembles **EOD** and **LIQ**. Closer examination shows that the differences between ensembles **EOD** and **LIQ** actually got smaller from the first through the third walk periods, perhaps reflecting the accumulating thermal strain over time with ensemble **EOD**.

Figure 7 presents the VO_2 data in units of $L{\cdot}min^{-1}$. Very little new information is conveyed regarding differences in clothing ensembles. Perhaps most noticeable is that VO_2 values for ensemble **LIQ** were consistently higher than for ensemble **EOD**. Nevertheless, during condition **34L**, VO_2 increased 5.24% in ensemble **EOD** from Walk 1 to Walk 3 while it decreased 2.69% with ensemble **LIQ**. Respective changes under condition **34H** were a 4.43% increase with ensemble **EOD** and a 0.44% increase with ensemble **LIQ**. Oxygen consumption is directly related to the total work load on the body including the additional energy expenditure required to cope with thermal stress (increased heart rate, sweating, etc.). The fact that VO_2 increased over time in ensemble **EOD** as thermal strain accumulated but decreased in ensemble **LIQ** as cooling progressed is yet another demonstration of the effectiveness of the Exotemp® liquid cooling system.

Figure 8 shows the VO_2 data corrected for the total weight of the man/clothing system. Statistically, there were no significant differences between clothing ensembles under any test condition, indicating that the efficiency of oxygen utilisation was not affected by the clothing being worn. This is a bit surprising in that one might have expected a change in the efficiency of motion between ensemble **STD** and the the others due to the weight and stiffness of the EOD clothing. Presumably, the weight is well distributed and movement is not compromised excessively despite the stiffness of the suit.

Comparison across the three panels in each of Figs. 6 – 8 shows that environmental condition had a small effect on the metabolic parameters, with

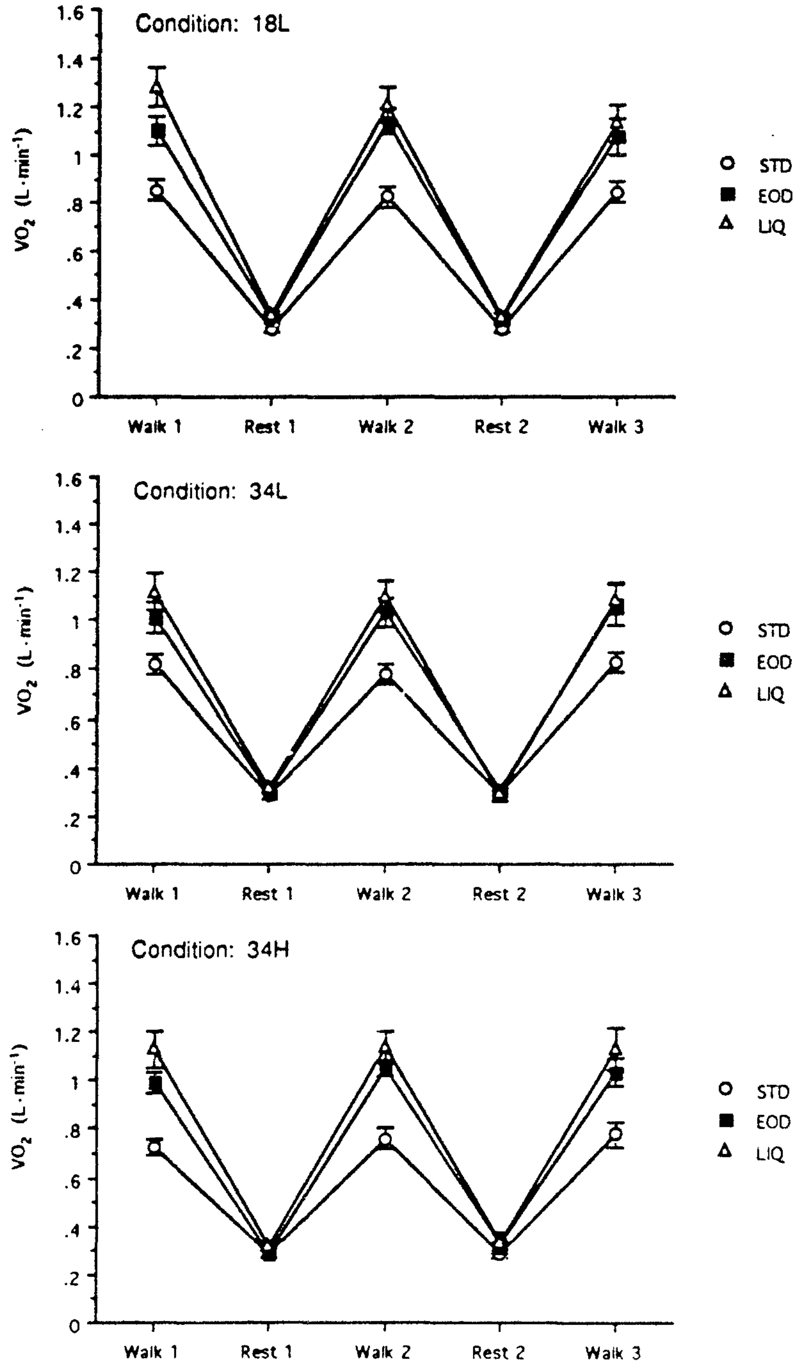


Figure 7. Mean oxygen consumption (VO_2) as a function of activity for three clothing ensembles and three environmental conditions.

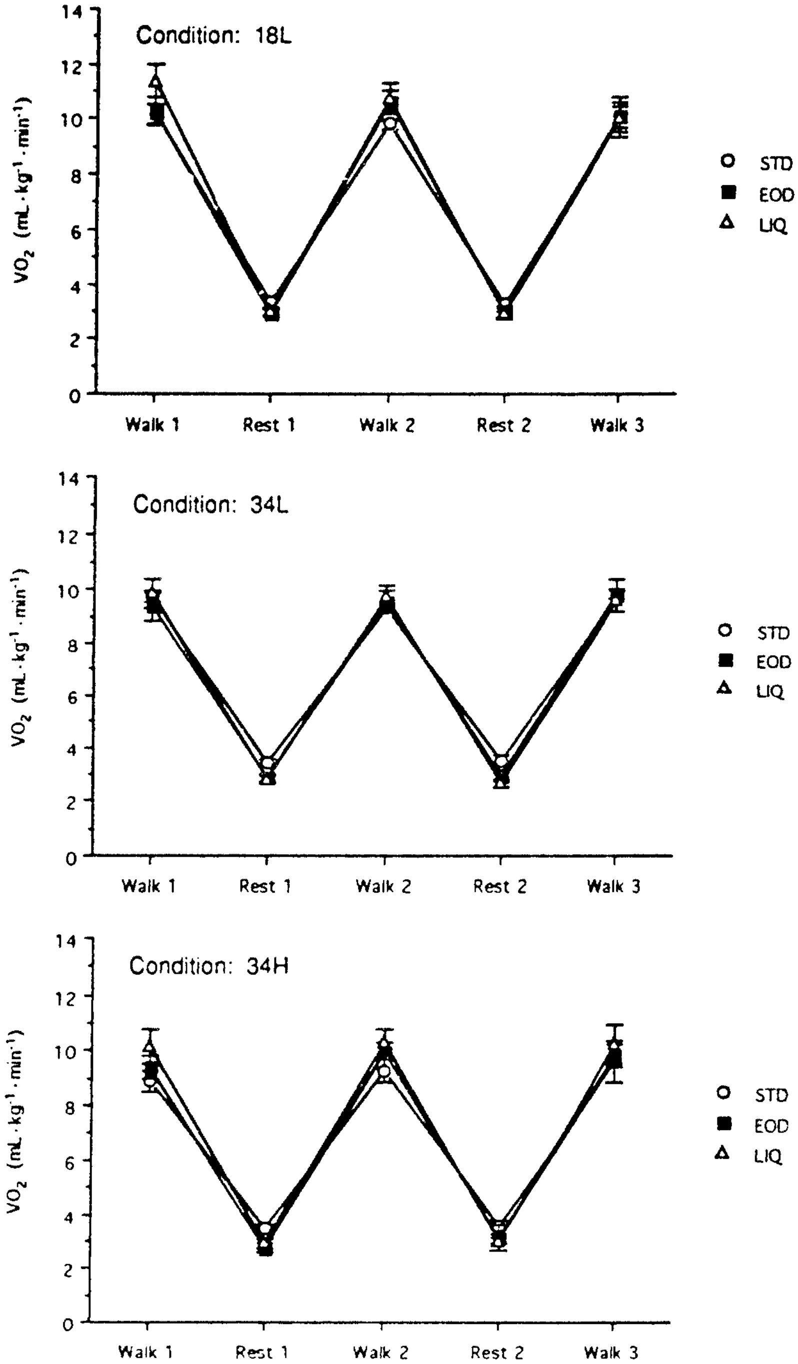


Figure 8. Mean oxygen consumption (VO_2) corrected for total weight carried as a function of activity for three clothing ensembles and three environmental conditions.

values under condition **18L** being slightly higher than under conditions **34L** and **34H**. The smaller differences in values between **34L** and **34H** vs. the larger differences between **34L** and **18L** suggests that the effect may be due to ambient temperature, but not relative humidity. However, all subjects followed the same sequence of environmental conditions from **18L – 34H**. One cannot, therefore, rule out the possibility that the changes between conditions are a reflection of some sort of acclimation process.

Subjective Parameters

The subjective data gathered in this study are probably the least reliable of any data. They are susceptible to individual interpretations of the meanings of the sensation descriptors and the ranges they represent, preconceptions as to how ratings should change over time with various clothing ensembles and environmental conditions, a learning curve of familiarisation with the terms, and perhaps even a perceived "peer pressure" as to one's tolerance for stress (the latter concern should not be a major factor in this study because paired subjects were never dressed simultaneously in the same ensemble). Nevertheless, subjective data can be important in the final analysis, for no matter how good the objective data are, the user of the clothing must feel comfortable with and have confidence in his equipment in order to wear it.

Figure 9 presents the thermal comfort scores as a function of time for the three clothing ensembles separately under each environmental condition. There were no statistically significant differences between clothing ensembles under condition **18L**, nor did the thermal comfort ratings change significantly over time. In contrast, both time and clothing ensemble were significant factors at both **34L** and **34H** ($p \leq 0.0325$). Suffice it to say that thermal comfort scores increased over time, and that subjects reported lower scores when wearing ensemble **LIQ** than when wearing either of the other ensembles. As to whether they were always more "comfortable" with ensemble **LIQ**, some subjects were too cold under condition **18L** due to the use of a fixed pump speed, and the pumps were very occasionally turned to a slower speed. Overall, the results

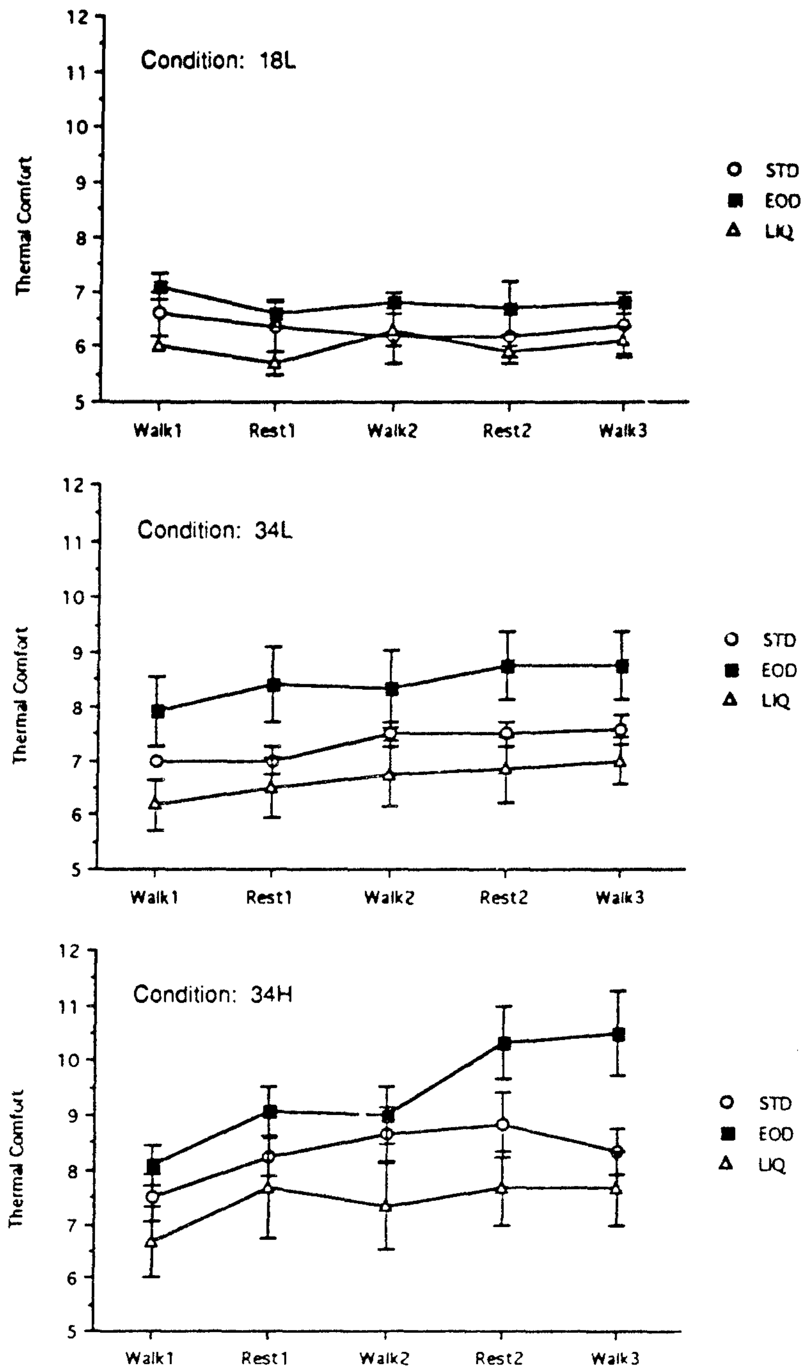


Figure 9. Thermal comfort as a function of activity for the three clothing ensembles and three environmental conditions.

suggest that the Exotemp® system is beneficial and desirable.

The relative perceived exertion results are presented in Figure 10. The statistical findings were less clearly defined for this parameter, showing a significant main effect of clothing under conditions **18L** ($p=0.0259$) and **34L** ($p=0.0206$), and a significant main effect of time under condition **34H**. Overall, perceived exertion was least when wearing ensemble **STD**, probably reflecting the fact that subjects were not carrying the weight of EOD suit at that time. As to the benefits of the cooling system, perceived exertion was generally lower with ensemble **LIQ** than with **EOD**, although still higher than with **STD**.

With regard to both subjective parameters, note that the values reported during the rest periods were not lower than during the work periods. In contrast to the HR and metabolic data which did decrease during rest periods, the subjective data indicate that perceived sensations may have a longer "decay time" and may accumulate over time. Perhaps a longer rest interval would have resulted in lower resting scores; alternatively, subjective scores solicited closer to the ends of the rest periods and may have presented a different picture.

STD / EOD / LIQ Summary

All of the foregoing data demonstrate three points clearly and repeatedly:

1. EOD work in itself may not be overly stressful from a thermal physiological strain perspective if conducted in normal station dress. However, even this relatively light work load results in increased thermal strain as ambient temperature and humidity increase.

2. Performing the same work in the very heavy EOD suit increases the physiological strain in the body considerably and results in intolerable levels of stress when temperature and humidity are high.

3. The Exotemp® liquid cooling system is able to relieve the

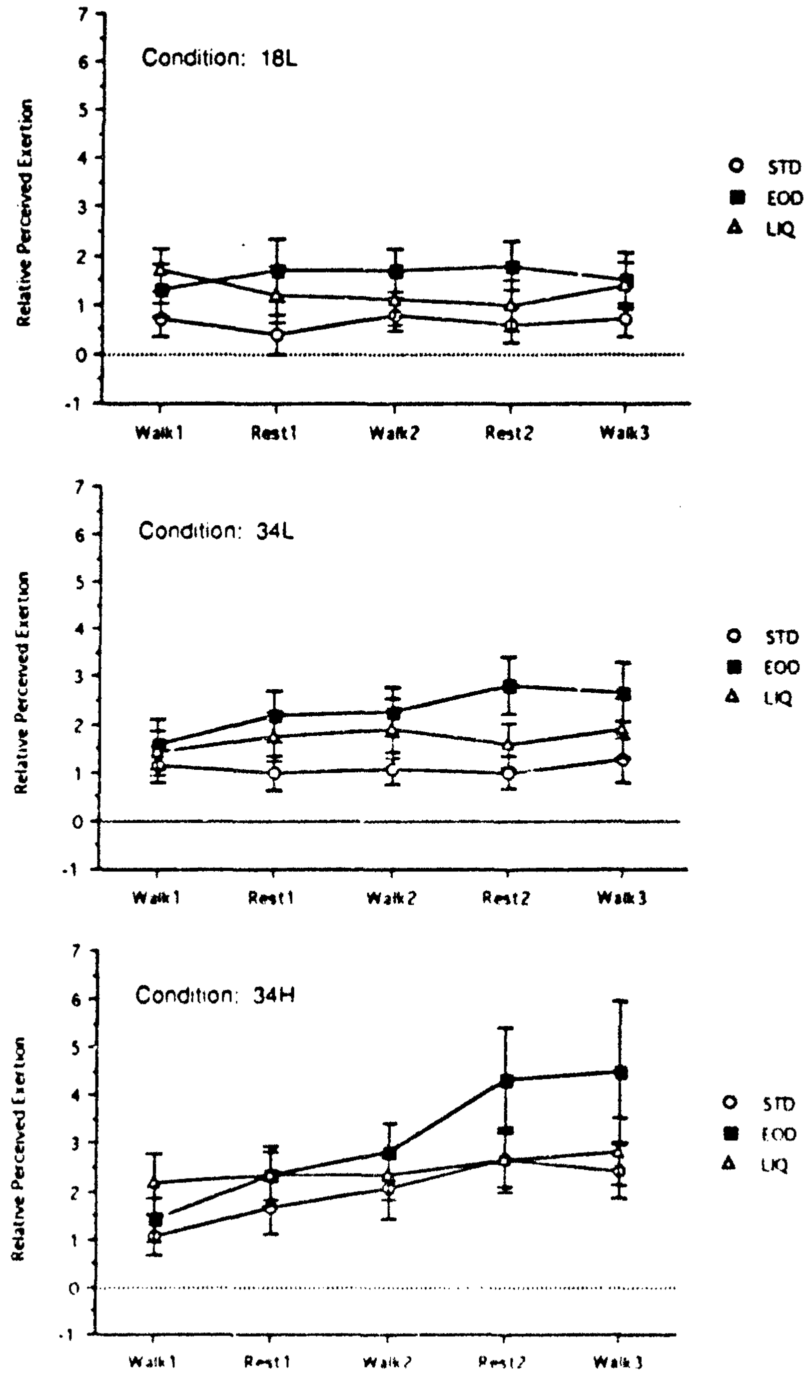


Figure 10. Relative perceived exertion as a function of activity for the three clothing ensembles and three environmental conditions.

physiological strain in the body to the extent that it is comparable to performing the same duties in normal station dress.

Clearly, the Exotemp® liquid cooling system is a useful addition to the EOD suit during work in hot environments.

LIQ / RIB / AIR Comparisons

The intent of this section is to compare the effectiveness of the **LIQ** ensemble with that of the two air cooling approaches (ensembles **RIB** and **AIR**). Constraints of the experimental design make these comparisons somewhat complicated. Since scheduling group **B** did not use the air vest at all, only group **A** data (i.e., essentially the younger subjects) can be used in such an analysis. Even then, since not all subjects wore all three cooling ensembles, it is impossible to compare them simultaneously while retaining the advantages of a repeated measures analysis for small subject sample sizes.

The approach adopted was to compare only ensembles **RIB** and **AIR** under all three environmental conditions using a one-within factor (condition) one-between factor (clothing) repeated measures analysis to first establish if there were any differences between the two air cooling approaches. Should no differences be found, the data could be combined and treated as a single air cooling modality for comparison with ensemble **LIQ**. This approach would also raise the number of subjects in all comparisons to seven, rather than four and three for the **RIB** and **AIR** ensembles, respectively.

Rectal Temperature Responses

The preliminary comparisons between ensembles **RIB** and **AIR** showed no statistically significant effects of clothing on $T_{re\text{-}i}$, $T_{re\text{-}f}$, or ΔT_{re} ($p=0.8707$, $p=0.8243$, $p=0.9867$, respectively). The data were thus combined as a single **RIB-AIR** treatment and compared to the other ensembles using a repeated measures analyses with seven subjects.

The upper panel of Figure 11 presents the ΔT_{re} data for the four clothing ensembles **STD**, **EOD**, **LIQ**, and **RIB-AIR** under the three environmental conditions. Since the statistical comparisons between ensembles **STD**, **EOD**, and **LIQ** have already been done, they are not repeated here; the data bars are, however, included in the graph for reference. It is quite apparent from this figure that the rise in rectal temperature due to wearing the EOD suit was hardly suppressed with the **RIB-AIR** ensemble(s). While the mean ΔT_{re} for **RIB-AIR** was slightly lower than for ensemble **EOD** during the warmer conditions, the differences were not significant ($p \geq 0.22$). There is certainly no comparison with the cooling capacity of the **LIQ** ensemble, and one would conclude that the **RIB** and **AIR** systems were of little use with respect to deep body temperature responses. Because of the similarities in Tre-i for all exposures, the results and conclusions for $T_{re\text{-}f}$ are very similar to those of ΔT_{re} and are not shown.

Mean Skin Temperature Responses

As with the rectal temperature data, there were no statistically significant differences in mean skin temperature parameters between ensembles **RIB** and **AIR**; thus the data were again combined and treated as a single **RIB-AIR** cooling modality.

The lower panel of Fig. 11 presents the ΔMST data for the four clothing ensembles **STD**, **EOD**, **LIQ**, and **RIB-AIR** under the three environmental conditions. Ensemble **RIB-AIR** was significantly different from ensemble **EOD** under condition **18L** ($p=0.0098$), but not under the warmer conditions ($p \geq 0.13$). One would conclude from these results that wearing the **RIB-AIR** ensemble(s) in the heat provided no significant benefit in terms of body surface cooling compared to wearing the EOD suit without a cooling system. MST_f data (not shown) corroborate these conclusions.

Since the thermal data indicated virtually identical physiological responses between ensembles EOD and RIB-AIR, it appeared pointless to pursue any

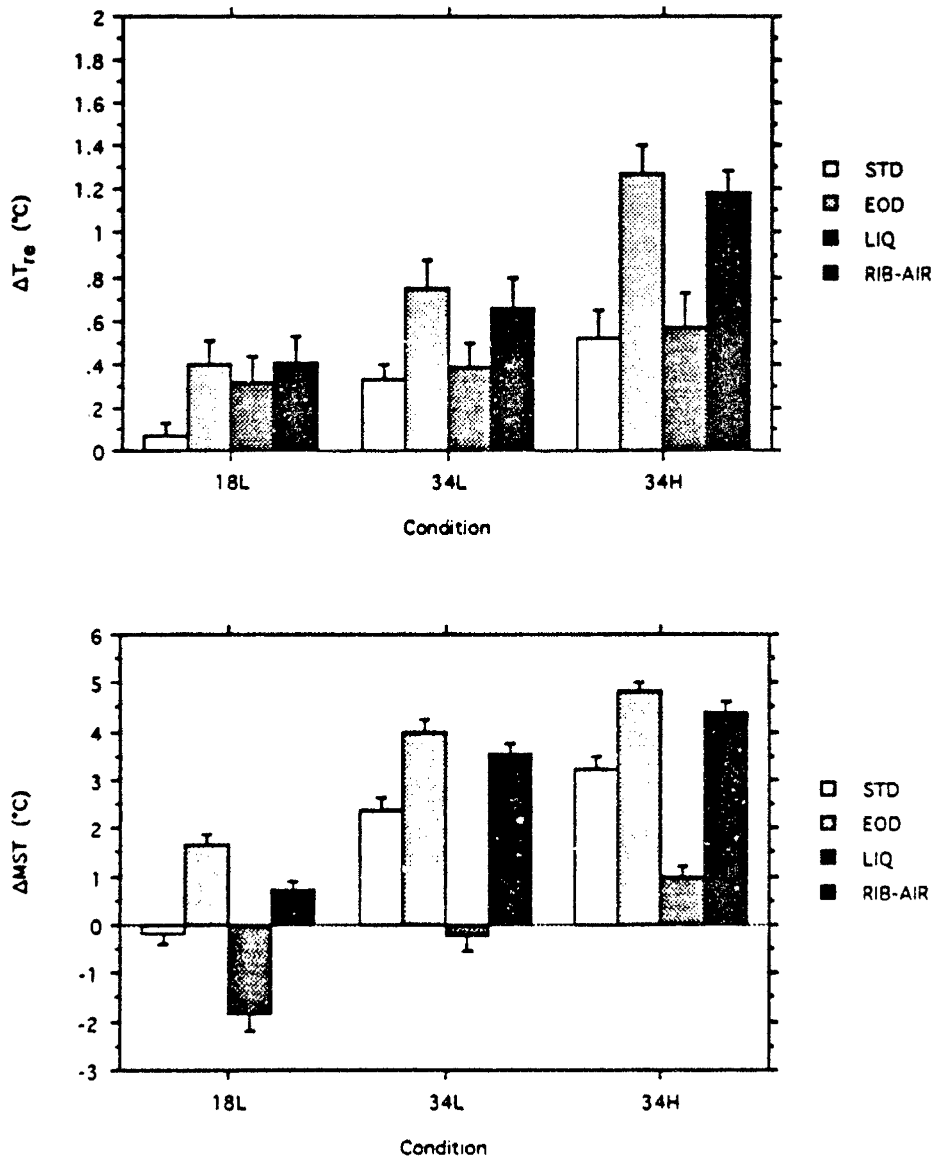


Figure 11. Mean change in rectal temperature (ΔT_{re}; upper panel) and mean change in mean skin temperature (ΔMST; lower panel) as a function of Condition for four clothing ensembles (ensembles **RIB** and **AIR** have been combined into a single modality; see text).

"merits" of air cooling, and no further comparative analyses of these data were carried out.

LIQ / RIB / AIR Summary

Clearly, the air cooling approaches as used in this study were of no physiological benefit in relieving thermal strain with the EOD suit. The passive ribbed vest can provide an air gap under the EOD clothing if it can resist compression. This air gap could potentially increase the total clothing insulation if the air were trapped, or it could increase convective and/or evaporative cooling if air were moving through the gap. The results of the present study showed no increase in thermal strain, suggesting that the vest was not trapping air to the extent that insulation was being increased. However, there was also no significant cooling effect, suggesting that air movement in the gap was perhaps insufficient. Given the stiffness of the EOD suit and the somewhat slow pace of body movements, it is not surprising that there was little if any "pumping" effect.

The active air vest used in this study has previously been shown to provide significant relief from thermal strain when supplied from a cool (13°C) air source (5). However, in the present study, the same vest supplied with uncooled ambient air at 34°C provided no apparent benefit. The obvious conclusion is that cooler air improves the performance of the air vest. Similar findings have been reported by others using different designs of air vest (14). One study did report some benefits of ambient air cooling, but only when coupled with conditioned air cooling during rest periods (15).

Since provision of conditioned air in a portable pack is difficult, and since EOD personnel can remove their suits during rest periods, air cooling does not seem like a practical solution for EOD work. The Exotemp® liquid cooling system was clearly functional and superior to the air vest in relieving thermal strain and would be the system of obvious choice.

Age Comparisons: Group YNG vs Group OLD; Condition 34L

A secondary objective of this study was to compare thermophysiological strain during EOD work in younger and older police officers; hence the recruitment of subjects in two age categories. Although both groups were tested with clothing ensembles **STD**, **EOD**, **LIQ**, and **RIB** under condition **34L**, only four subjects of group **YNG** wore the **RIB** ensemble. Comparisons between age groups involving all four clothing ensembles can, therefore, only be done with four of the younger subjects. An alternative approach is to ignore ensemble **RIB** in these analyses, bringing the subject numbers to six in group **YNG** and five in group **OLD**. Considering that ensemble **RIB** was of no benefit and that the age questions would best be resolved by maximising the number of subjects in each age group, the latter approach was adopted.

The results for group **YNG** were much the same as those already presented for condition **34L** since the only change was the transfer of one subject from schedule group **A** to age group **OLD**. To minimise redundancy, fewer graphs are presented in this section and comparisons are limited to the objective parameters of physiological strain.

Rectal Temperature Responses

The upper and lower panels in Figure 12 present the mean $T_{re\text{-}f}$ and ΔT_{re} data, respectively, in the three clothing ensembles for the **YNG** and **OLD** subjects. Age did not have a significant effect on $T_{re\text{-}f}$ ($p=0.1945$), but it did significantly influence ΔT_{re} ($p=0.0255$). There was no significant interaction between clothing and age for either parameter, indicating that clothing effects were similar for both age groups.

The average ΔT_{re} across all three clothing ensembles was 0.44±0.07°C for group **YNG** compared to 0.74±0.07°C for group **OLD**. This 0.3°C difference in ΔT_{re} between groups is already 50% of the increase in core temperature (0.6°C) believed by some to lead to performance decrements (10, 11). From these

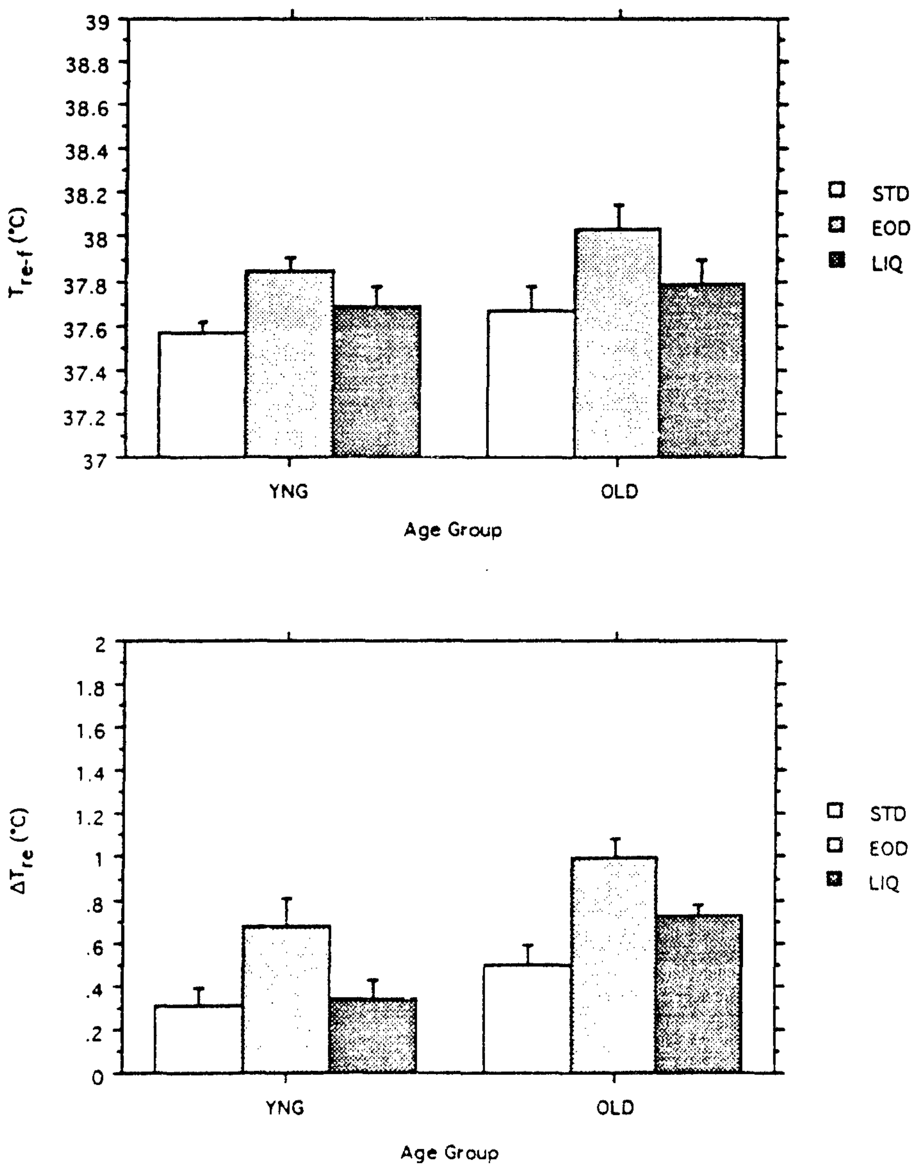


Figure 12. Mean final rectal temperature (T_{re-f}; upper panel) and mean change in rectal temperature (ΔT_{re}; lower panel) as a function of Age Group for three clothing ensembles. All data are from condition **34L**.

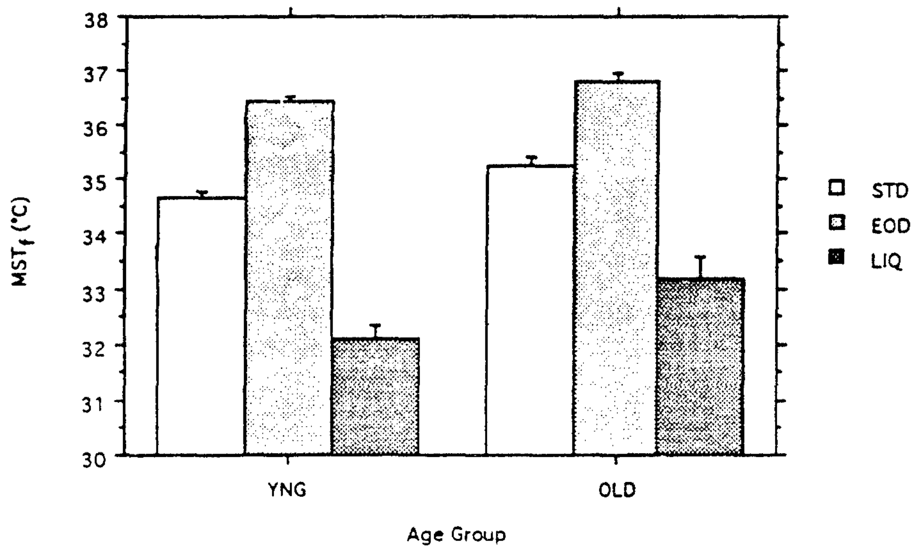
results, it appears that older subjects may be slightly more susceptible to thermal strain (specifically, an increase in deep body temperature) than their younger counterparts.

Considering only the data for ensemble **EOD**, ΔT_{re} was 1.00±0.08°C for group **OLD** but only 0.68±0.13°C for group **YNG**, for a difference of 0.32°C. While the increase in the older subjects was greater than that in the younger subjects, both groups still showed considerable elevation in temperature with the EOD suit. By comparison, when wearing ensemble **LIQ**, ΔT_{re} was 0.73±0.05°C for group **OLD** but only 0.33±0.10°C for group **YNG**, for a difference of 0.40°C between groups. While the older subjects still exhibited considerable thermal strain even with liquid cooling, the younger subjects showed much less strain in this condition. These results may be indicative of a difference in thermoregulatory capacity as a function of age (8, 9, 16), with younger individuals being able to better utilise the heat dissipating capacity of the liquid cooling garments.

Mean Skin Temperature Responses

The upper and lower panels in Figure 13 present the mean MST_f and ΔMST data, respectively, in the three clothing ensembles for the **YNG** and **OLD** subjects. Age had a very significant effect on MST_f ($p=0.0061$) and an almost significant influence on ΔMST ($p=0.0521$). Again, there was no significant interaction between age and clothing. As might be expected from the core temperature results, the older subjects showed higher skin temperatures than the younger subjects, indicating slightly more thermal strain in older subjects as measured by these parameters.

Looking more specifically at the age-related MST responses in the individual clothing ensembles, the most interesting observation is that over the course of the exposure in the **LIQ** ensemble MST decreased in younger subjects while it still increased in the older subjects. This supports the comments made previously that younger subjects may be better able to utilise the heat



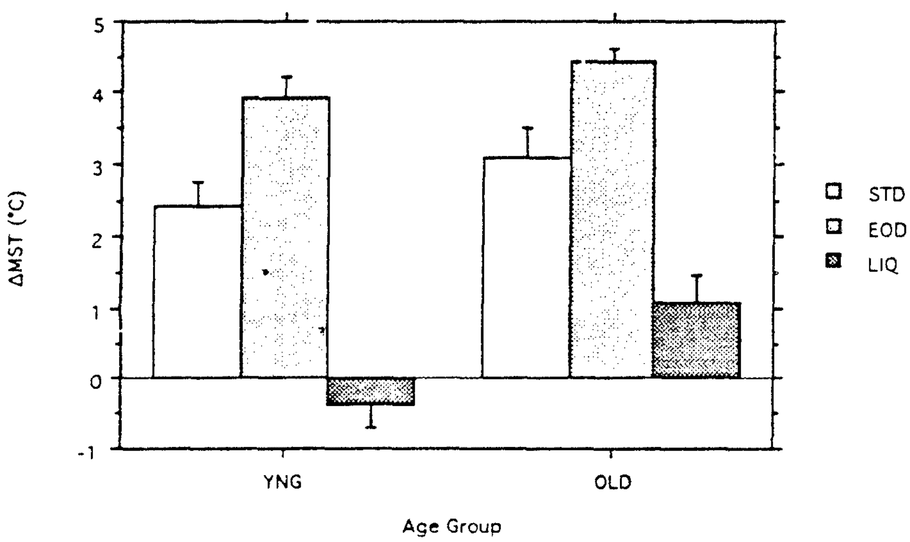


Figure 13. Mean final mean skin temperature (MST_f; upper panel) and mean change in mean skin temperature (ΔMST; lower panel) as a function of Age Group for three clothing ensembles. All data are from condition **34L**.

dissipating capacity of the liquid cooling garments, due perhaps to better cutaneous blood circulation.

Body Weight Changes

All four body weight change parameters were examined for statistically significant effects of age, but none were found. Despite this, there were some interesting differences. Mean FLOSS values were virtually identical at about 0.55 kg (range 0.54–0.56 kg) in ensembles **STD** and **LIQ** for both **YNG** and **OLD** subjects. However, with ensemble **EOD**, younger subjects showed an average 1.30±0.17 kg fluid loss while older subjects only lost 0.94±0.19 kg of fluid (28% less). These data suggest that both younger and older subjects were perhaps able to achieve the rate of sweat output required to adequately reduce thermal strain with ensembles **STD** and **LIQ**, but that with ensemble **EOD** the sweat output of the older subjects may have been inadequate. This idea is supported by the slightly higher degree of thermal strain in the subjects of group **OLD** as indicated by their higher rectal and skin temperatures. Alternatively, perhaps a more substantial thermal stress, such as that imposed by ensemble **EOD** without cooling, was required to bring out the age-dependent differences in sweat production capability. Had this difference been statistically significant, it would have shown up as a significant age-clothing interaction, but none was found.

The FEVAP data showed virtually no differences between age groups with ensembles **EOD** and **LIQ**, but FEVAP was about 33% higher with ensemble **STD** in group **OLD** compared to group **YNG**. This could be explained by noting that skin temperatures were higher in the older subjects and, when combined with a more permeable garment such as ensemble **STD**, could have led to more sweat evaporation from the body (i.e., a greater thermal drive to evaporate moisture). This higher degree of sweat evaporation coupled with the reduced sweat output resulted in a slightly higher E/P for the older subjects, especially in ensemble **STD**. However, as above, a significant interaction would have been seen if this difference were statistically significant.

Heart Rate Responses

Heart rate data averaged over the duration of each exposure for each clothing ensemble showed mean values about 10 bpm higher in older subjects compared to younger subjects, but none of the differences were statistically significant. This is probably because standard deviations were in the order of 15–20 bpm. Examination of group means at each activity period indicated that older subjects always had heart rates slightly higher than the younger subjects. However, during the final lift period in ensemble **EOD**, HR values were 132.4±6.5 bpm for group **YNG** and 139.6±2.6 bpm for group **OLD**. This difference is neither statistically nor physiologically significant.

Metabolic Responses

Metabolic data were also analysed for age effects, but no significant differences were found. No further analyses of metabolic data were done.

Age Comparison Summary

In summary, the temperature data indicated slightly higher levels of thermal strain in some parameters in older vs younger subjects. The differences were, however, not all that large and were not supported by significant age-dependent differences in other temperature parameters. Most interesting was the fact that heart rates were not greatly different between the two age groups. Similar results were, however, also reported by Smolander *et al* (17) working with subjects of 34 y and 57 y mean age, and he concluded that "older calendar age is not necessarily associated with a reduced ability to exercise in a hot environment and other factors, such as physical activity habits and aerobic capacity, may be equally important in determining heat tolerance in the elderly".

One would conclude that the present study did not show a clear age-dependence of thermal physiological strain, but it must be remembered that the age difference between the groups was not that large. On tne other hand, perhaps the overall age range was quite realistic for and representative of police officers conducting EOD work.

SUMMARY AND CONCLUSIONS

This study examined the physiological responses of the body during representative EOD work in the heat. The baseline exposures conducted with standard clothing at 18°C and 40% relative humidity (condition **18L**) indicated that there was little physiological strain associated with the tasks themselves. However, increasing the environmental stress by changing the conditions to 34°C @ 40% rh (condition **34L**) or 34°C @ 80% rh (condition **34H**) resulted in minor but noticeable increases in physiological strain.

Wearing the EOD suit imposed a considerable stress on the body simply due to the weight of the clothing itself, as shown by the increased strain under condition **18L**. This stress was compounded when ambient temperature and humidity were increased, and resulted in reduced work tolerance times under condition **34H**. Clearly, EOD work cannot be conducted safely and efficiently under these circumstances.

The Exotemp® BD-1 Pro-Kool Personal Cooling System worn under the EOD suit in the heat was able to reduce the thermal physiological strain to levels comparable to not wearing the EOD suit at all. Significant reductions were seen in body temperatures, sweat output, heart rates, metabolic rates, and subjective scores of thermal comfort and physical exertion. This liquid-cooled portable cooling system is highly compatible with the EOD suit and is recommended for EOD work in the heat.

Two other cooling approaches involving air were also examined. A thickly-ribbed nylon vest which operates entirely passively and a blower-driven air vest were both unsuccessful in reducing thermal strain. The ribbed vest probably created an air space beneath the EOD suit, but there was likely not enough air movement in this space to enhance evaporation of sweat. The active air vest overcame the problem of air movement by blowing ambient air under the EOD suit, but did not show significant benefits over the ribbed vest. Since this same air vest has been shown to significantly reduce thermal strain when supplied with cool air, one must conclude that cool air is required for its successful alleviation of thermal strain. Lightweight portable cool air sources are not easy to design and we are not aware of any such units that would be compatible with the EOD suit. Neither of these systems is, therefore, recommended for use with the EOD ensemble.

This study also intended to examine the influence of age on physiological responses to EOD work in the heat. Although two groups of subjects were recruited, the age separation was not very large. Minor differences in some parameters were observed between the groups, with younger subjects tending to have slightly lower levels of strain relative to the older subjects. The differences were, however, for the most part not statistically significant. If the subject sample of this study is representative of the general population of EOD personnel, it would appear that age effects on physiological responses are relatively minor.

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APPENDIX A

Tables of Numerical Results

Table A1. Summary of Physiological Parameters at Termination of Exposures: STD / EOD / LIQ Ensemble Comparisons

Parameter	Condition	Clothing STD	Clothing EOD	Clothing LIQ
Tre-f (°C)	18L	37.40 ± 0.10	37.72 ± 0.07	37.66 ± 0.10
	34L	37.58 ± 0.04	37.86 ± 0.06	37.66 ± 0.08
	34H	37.70 ± 0.08	38.42 ± 0.18	37.81 ± 0.04
ΔTre (°C)	18L	0.07 ± 0.05	0.40 ± 0.11	0.32 ± 0.12
	34L	0.33 ± 0.07	0.75 ± 0.13	0.39 ± 0.10
	34H	0.52 ± 0.12	1.27 ± 0.13	0.57 ± 0.16
MST-f (°C)	18L	31.60 ± 0.23	33.92 ± 0.19	30.68 ± 0.29
	34L	34.71 ± 0.12	36.44 ± 0.07	32.13 ± 0.20
	34H	35.69 ± 0.10	37.58 ± 0.21	33.72 ± 0.31
ΔMST (°C)	18L	-0.23 ± 0.19	1.65 ± 0.23	-1.89 ± 0.31
	34L	2.37 ± 0.27	4.01 ± 0.26	-0.28 ± 0.28
	34H	3.22 ± 0.27	4.83 ± 0.17	0.97 ± 0.24
FLOSS (kg)	18L	0.187 ± 0.021	0.714 ± 0.115	0.349 ± 0.046
	34L	0.543 ± 0.030	1.213 ± 0.165	0.516 ± 0.067
	34H	0.757 ± 0.060	1.574 ± 0.294	0.787 ± 0.163
%DEHY (%)	18L	0.234 ± 0.022	0.896 ± 0.142	0.433 ± 0.048
	34L	0.677 ± 0.018	1.514 ± 0.199	0.636 ± 0.071
	34H	0.944 ± 0.059	1.977 ± 0.378	0.966 ± 0.190
FEVAP (kg)	18L	0.129 ± 0.057	0.222 ± 0.043	0.145 ± 0.036
	34L	0.393 ± 0.023	0.407 ± 0.058	0.221 ± 0.027
	34H	0.304 ± 0.035	0.200 ± 0.095	-0.020 ± 0.048
E/P (%)	18L	55.4 ± 22.3	31.0 ± 3.9	44.0 ± 12.5
	34L	74.5 ± 7.2	36.0 ± 5.3	49.0 ± 10.5
	34H	40.6 ± 3.7	7.7 ± 6.3	-4.4 ± 9.3

Values are mean±SE derived from the 7 subjects of scheduling group A.

Table A2. Summary of Physiological Parameters recorded during Lift 3 (for HR) or Walk 3: STD / EOD / LIQ Ensemble Comparisons

		Clothing		
Parameter	Condition	STD	EOD	LIQ
HR (bpm)	18L	86.9 ± 4.8	110.4 ± 4.6	99.9 ± 4.5
	34L	94.2 ± 7.5	134.4 ± 5.8	104.9 ± 6.0
	34H*	103.1 ± 11.8	156.6 ± 8.2	112.0 ± 4.0
VE (L/min) (BTPS)	18L	25.1 ± 1.6	31.4 ± 1.6	33.3 ± 2.3
	34L	24.6 ± 1.6	32.9 ± 2.1	32.5 ± 2.2
	34H†	23.0 ± 2.2	35.2 ± 3.3	34.7 ± 3.5
VO2 (L/min) (STPD)	18L	0.85 ± 0.04	1.08 ± 0.08	1.13 ± 0.07
	34L	0.83 ± 0.04	1.07 ± 0.09	1.09 ± 0.06
	34H†	0.78 ± 0.05	1.04 ± 0.06	1.13 ± 0.09
VO2 (mL/kg/min) (STPD)	18L	10.07 ± 0.36	10.07 ± 0.72	10.06 ± 0.50
	34L	9.84 ± 0.14	9.79 ± 0.56	9.61 ± 0.39
	34H†	9.58 ± 0.77	9.82 ± 0.44	10.21 ± 0.70
TC (1 – 13)	18L†	6.4 ± 0.6	6.8 ± 0.2	6.1 ± 0.2
	34L◊	7.6 ± 0.3	8.8 ± 0.6	7.0 ± 0.4
	34H◊	8.3 ± 0.4	10.5 ± 0.8	7.7 ± 0.7
RPE (0 – 12)	18L†	0.7 ± 0.3	1.5 ± 0.5	1.4 ± 0.5
	34L◊	1.3 ± 0.4	2.7 ± 0.6	1.9 ± 0.6
	34H◊	2.4 ± 0.6	4.5 ± 1.5	2.8 ± 0.7

Values are mean±SE derived from the 7 subjects of scheduling group A except for:
* n=4; † n=5; ◊ n=6

Table A3. Summary of Physiological Parameters at Termination of Exposures: YNG vs OLD Comparisons

		Clothing		
Parameter	Age Group	STD	EOD	LIQ
Tre-f (°C)	YNG	37.57 ± 0.05	37.85 ± 0.06	37.68 ± 0.09
	OLD	37.66 ± 0.12	38.03 ± 0.11	37.78 ± 0.12
ΔTre (°C)	YNG	0.31 ± 0.08	0.68 ± 0.13	0.33 ± 0.10
	OLD	0.50 ± 0.09	1.00 ± 0.08	0.73 ± 0.05
MST-f (°C)	YNG	34.65 ± 0.12	36.47 ± 0.08	32.11 ± 0.24
	OLD	35.26 ± 0.15	36.82 ± 0.15	33.20 ± 0.37
ΔMST (°C)	YNG	2.44 ± 0.32	3.94 ± 0.30	-0.41 ± 0.29
	OLD	3.09 ± 0.42	4.43 ± 0.18	1.08 ± 0.39
FLOSS (kg)	YNG	0.557 ± 0.031	1.300 ± 0.166	0.558 ± 0.061
	OLD	0.540 ± 0.039	0.942 ± 0.187	0.546 ± 0.099
%DEHY (%)	YNG	0.683 ± 0.020	1.607 ± 0.209	0.682 ± 0.063
	OLD	0.670 ± 0.036	1.166 ± 0.223	0.670 ± 0.116
FEVAP (kg)	YNG	0.392 ± 0.027	0.408 ± 0.069	0.221 ± 0.031
	OLD	0.522 ± 0.034	0.410 ± 0.051	0.224 ± 0.050
E/P (%)	YNG	72.4 ± 8.2	32.3 ± 4.5	43.9 ± 10.2
	OLD	97.1 ± 4.0	47.6 ± 6.3	45.6 ± 12.5

Values are mean±SE derived from 6 subjects in group YNG, 5 subjects in group OLD

APPENDIX B

Photographs of Clothing Ensembles and Experimental Procedures

Figure B-1. Subject being prepared for physiological measurements. Twelve thermistors are taped to the skin at the forehead, chest, abdomen, forearm, hand, front thigh, shin, foot, calf, rear thigh, lower back, and upper back. The strap on the chest is for measurement of heart rate. A rectal probe (not visible) measures deep body temperature.

Figure B-2. Subject donning the Exotemp liquid cooling garment prior to putting on the EOD suit. The liquid tubing lines on the inner surface of the garment are clearly visible, as are the tubing connectors emerging from the subject's left side.

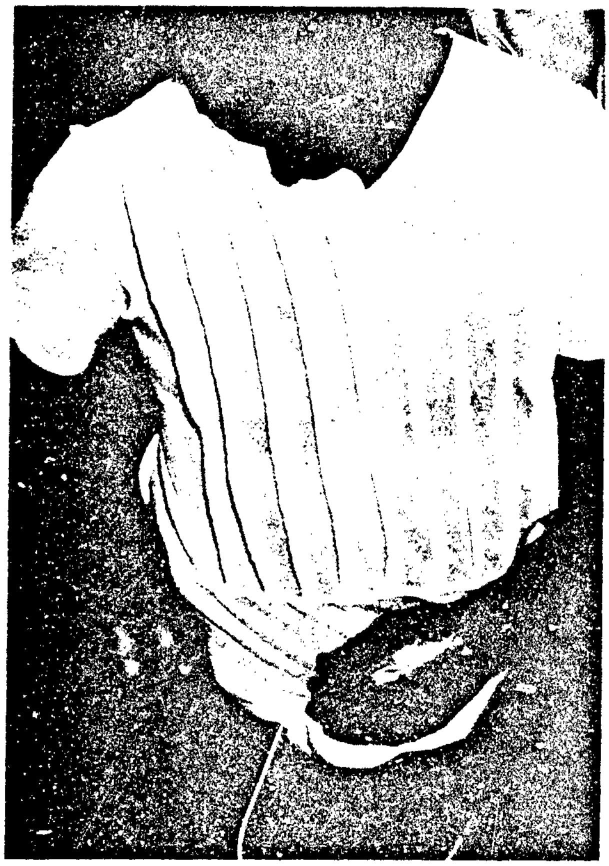

Figure B-3. Subject donning the ribbed vest prior to putting on the EOD suit. The thick ribs are padded to maintain an air space between the vest and the covering garments.

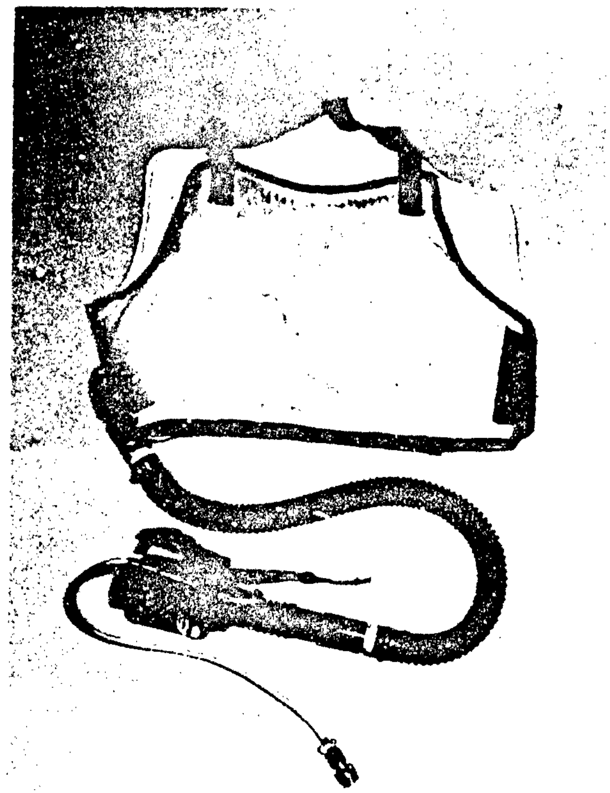

Figure B-4. Photograph of the DCIEM air vest originally developed for high performance aircraft. The vest is normally connected to a chilled air source in the aircraft. During this study, the vest was operated with ambient air by connecting it to the AR-5 Respirator Blower shown in the foreground.

Figure B-5. Subject performing the box carrying task while wearing the **STD** clothing ensemble. A light attached to the wall provided the timing signals for movement (4 moves per minute). A WBGT monitor is visible on the tripod at the right hand side of the photograph.

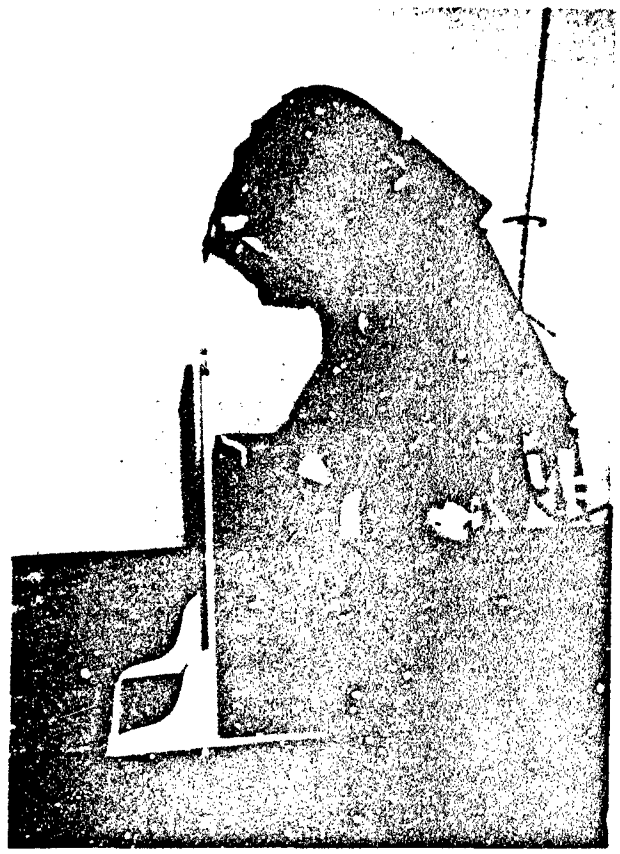

Figure B-6. Subject performing the box carrying task while wearing ensemble **LIQ**. The liquid supply lines from the cooling garment emerge through the EOD trousers at the subject's left side and are connected to the bottle of ice/water in the pouch strapped to the left thigh.

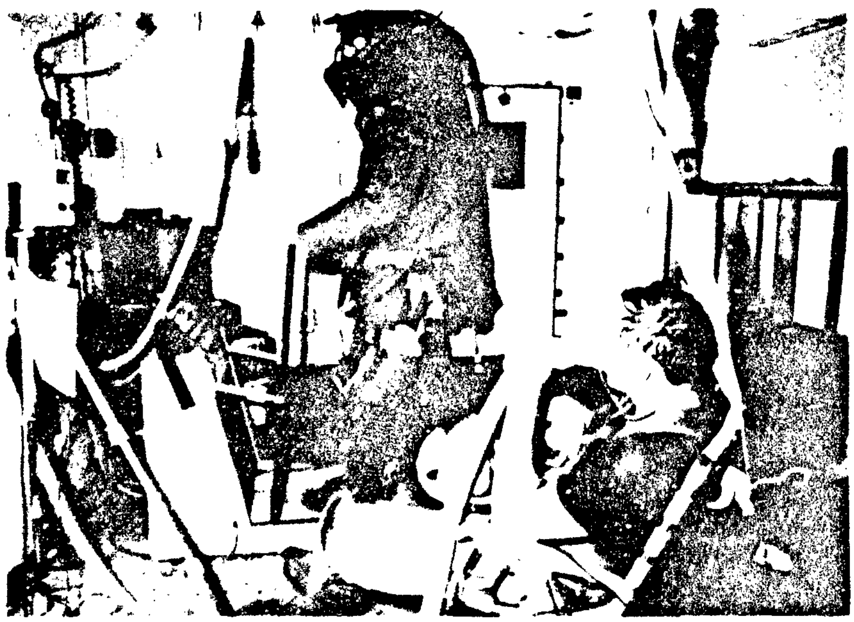

Figure B-7. Two subjects in the test chamber. The subject in the background wearing the EOD suit (with cooling) is walking on the treadmill at a speed of 3.5 km·hr^{-1}. The hose in front of him is for metabolic rate measurements during walking. The subject in the foreground is dressed in ensemble **EOD** (i.e., the EOD suit without cooling) and is providing a resting metabolic rate measurement with his EOD jacket and helmet removed.

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This study examined the capabilities of three technologies (a liquid cooled undergarment, a thickly-ribbed vest of hydrophylic nylon, and an air vest) to alleviate thermal strain in personnel working in Explosives Ordnance Disposal (EOD) clothing under environmental conditions of 18°C @ 40% relative humidity (rh), 34°C @ 40% rh, and 34°C @ 80% rh. Simulated EOD tasks consisted of treadmill walking (10 min), unstacking/carrying/stacking weighted boxes (10 min), and a rest period (15 min) with the EOD helmet and jacket removed repeated for a target duration time of 90 min. Physiological data included rectal temperature, skin temperature , heart rate , sweat production and evaporation, metabolic rate, and subjective evaluations of thermal comfort and perceived exertion. The results indicated that wearing the EOD suit produces significant increases in thermal physiological strain over performing the same tasks in a standard station uniform. However, the liquid-cooled Exotemp® personal cooling system was very effective in reducing that strain during heat exposure. Rectal temperatures, heart rates and fluid losses (dehydration) were reduced back to values comparable to those when not wearing the EOD suit, while skin temperatures were actually lower with the cooling system than with only the station uniform. Subjects indicated reduced perceived exertion levels and improved thermal comfort when wearing the liquid-cooled garment with the EOD suit. In contrast, the ribbed vest and air vest showed no significant benefits with the EOD suit. It is concluded that the increase in thermal physiological strain resulting from wearing the EOD suit during EOD work in hot environments can effectively be minimised by use of the Exotemp® personal cooling system.

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Heat Stress
Thermal Strain
Personal Cooling
Explosive Ordnance Disposal

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